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STUDY OF THE POTENTIAL FOR PROFITIBLE UTILIZATION OF PULVERIZED COAL FLYASH MODIFIED BY THE ADDITION OF LIMESTONE-DOLOMITE SULFUR DIOXIDE REMOVAL ADDITIVES

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TECHNICAL REPORT

Study Of The Potential For Profitable Utilization
Of Pulverized Coal Flyash Modified By The
Addition of Limestone-Dolomite Sulfur
Dioxide Removal Additives

FINAL REPORT

Contract No. PH 86-67-122

National Air Pollution Control Administration
Department of Health, Education and Welfare

COAL RESEARCH BUREAU
MINERAL INDUSTRIES BUILDING
WEST VIRGINIA UNIVERSITY
Morgantown, West Virginia

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Final Report

On

Study of the Potential for Profitable Utilization of Pulverized Coal Flyash Modified by the Addition of Limestone-Dolomite Sulfur Dioxide Removal Additives

To

National Air Pollution Control Administration
(Contract No. PH 86-67-122)
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SUMMARY

The process currently receiving major emphasis by the National Air Pollution Control Administration (NAPCA) as a means of reducing sulfur oxides emission at coal burning power stations is the limestone or dolomite injection process for fixing gaseous sulfur oxides as solid calcium and magnesium sulfates. One of the detriments to limestone or dolomite injection is the increase in solid wastes produced since the amount of flyash to be disposed of would be approximately doubled. Moreover, the flyash produced would be of little value in conventional flyash utilization schemes because of the large increases in lime, magnesia and sulfur.

The objective of this contract was to determine the potential for profitable utilization of this modified flyash, resulting from limestone or dolomite injection, by characterizing the physical and chemical properties of the material, performing utilization tests and, where feasible, initiating utilization studies.

The chemical composition and physical characteristics of the modified flyashes examined and the test conditions under which the ashes were produced are described. In determining the utilization potential, modified flyash was separated by sizing, specific gravity, magnetic, electrostatic and surface chemical (flotation) properties in attempts to concentrate usable minerals. In addition, the whole material and some size fractions were heat treated to determine the potential for recovering iron, producing mineral wool and sintered aggregate. Leaching tests to recover aluminum were also undertaken. In addition, the utilization potential of modified flyash in soil stabilization, concrete admixtures, acid mine drainage neutralization, and soil amendments were also studied.

Two developments of this study involving concentration to recover lime and melting to yield sulfur derivatives and mineral wool have been linked together to form a preliminary conceptual plan for an Emission Control Minerals Complex (ECMC) to utilize all parts of modified flyash. The ECMC process involves slurrying modified flyash with water followed by (a) carbonation of the slurry to convert unreacted lime and magnesia to their carbonate form, (b) concentration of lime from the carbonated modified flyash by agglomerate flotation for reinjection into the furnace, (c) melting of the concentration rejects for the manufacture of such products as mineral wool, and (d) recovery of the relatively clean and more concentrated sulfur gases evolved from the melt for the manufacture of such products as sulfuric acid.

In addition to the ECMC process several other potentially successful utilization methods were tested. However, these were of lesser potential because of physical, chemical or marketing limitations. It was determined that modified flyash had advantages over lime for acid mine drainage neutralization because of decreased sludge settling and filtering time. However, the greater amounts of modified flyash required and the transportation distances likely to be involved would greatly reduce the potential for succesful implementation of this utilization scheme.

Modified flyash was also found to be of use in concrete admixtures since the strength of concrete and lime-modified flyash mixtures attained good compressive strengths. However, the attainment of other physical requirements varied and would therefore require that each modified flyash be tested empirically to determine its acceptability for a particular application.

Utilization of limestone modified flyash in cement kilns also has potential because it could supply a portion of both the argillaceous and calcareous components. Dolomite modified flyashes could not be used because of limits on the amount of magnesia in portland cement. The utilization of some limestone modified flyashes could also be restricted in this area because of limits on the amount of iron oxide in the resultant portland cement.

The use of modified flyash in soil stabilization and as a soil amendment was found to have potential. The lime to flyash ratio required to stabilize most soils is already available in modified flyash so that no additional lime would be required. It would be necessary to determine optimum proportions for each application in this area because of the wide variety of soils and the interdependence of soil, lime and flyash components. Greenhouse studies under standard methods of application indicated that dolomite modified flyash (DD), when used as a soil amendment, gave good yields of fescue at the lowest application rate of any of the flyashes listed.

Research is continuing on NAPCA contract 22-68-18 to more fully determine the feasibility of recovering lime for reinjection, the cementation properties of modified flyash and to perform pilot tests on the utilization schemes of lesser potential as warranted.

ACKNOWLEDGMENTS

As a result of past and existing cooperative arrangements between the Coal Research Bureau and other research organizations, it was possible to obtain extensive consultation and experimental testing services in the performance of this work at minimal cost. We wish to acknowledge and to thank the following organizations for their help: Bituminous Coal Research, Monroeville, Pennsylvania; School of Mines, West Virginia University; United States Bureau of Mines, Morgantown and Pittsburgh Research Centers; West Virginia State Road Commission, Morgantown Testing Laboratory.

INTRODUCTION

Air pollution by sulfur oxide emission as a result of combustion and related heat treating methods of sulfur bearing materials is receiving considerable attention because of the threat posed to health on a nationwide basis.(1) A significant amount of the sulfur oxides emitted are from coal burning power stations. As a means of eliminating or substantially reducing these emissions, the Division of Process Control Engineering (DPCE) of NAPCA is studying sulfur oxide emission from coal burning power stations with the aim of developing processes to remove sulfur from the coal before combustion or to remove the gaseous sulfur oxides from the stack gases.(2) The process currently receiving most attention involves the injection of limestone or dolomite into the utility boiler to fix the gaseous sulfur oxides as solid calcium and magnesium sulfates.(3,4) Disposition of the large quantities of solid residues, primarily flyash, produced at coal burning power stations is already a problem and it is estimated that flyash production will increase from the current level of approximately 25 million tons per year to approximately 45 million tons by 1980.(5) This estimate, however, does not consider the possible increase in flyash production as a result of injecting limestone or dolomite to prevent sulfur oxide emission. Power stations that inject limestone or dolomite would be expected to substantially increase their solid residue output above those projections by the production of about equal amounts of calcined, sulfated limestone or dolomite. For example, with typical steam coals (eg, two to four percent sulfur and eight to ten percent ash), the injection of 100 percent of the stoichiometric amount required to convert all sulfur oxides present in the flue gases to solid sulfates would approximately double the amount of flyash normally generated during combustion of this same coal. Moreover, the flyash that would result would be unlike flyashes currently produced because of large increases in lime, magnesia and sulfates of lime and magnesia. Thus, the elimination of air pollution by sulfur oxides using limestone or dolomite injection could result in a larger solids disposal problem.

The purpose of this study was to determine the potential for profitable utilization of these modified flyashes by (a) characterizing the chemical composition and physical properties and (b) investigating the potential for producing salable products by the application of mineral dressing and other beneficiation procedures. Since limestone and dolomite modified flyashes would represent entirely new materials, the problem was approached in a manner that would develop the most detailed information about individual components. The physical and chemical characteristics of each modified flyash sample were determined by standard analytical techniques except when the nature of this material required modification of standard tests. The test program to determine the best methods of utilization consisted of all the major physical separation techniques (eg, sizing, specific gravity, magnetic, electrostatic and flotation), heat treatment and smelting techniques for iron, mineral wool and aggregate production, leaching tests for aluminum production, pozzolanic property tests in concrete admixtures, soil tests for stabilization and amendment properties and neutralization tests with acidic mine water.

The characterization and utilization test program was initially planned from the standpoint of concentrating both metallic and non-metallic materials that might report in modified flyash in a free state as a result of reactions

TABLE 1

Chemical and Physical Properties of Modified Flyash and Normal Flyash Generated During Detroit Edison-Combustion Engineering Tests at St. Clair, Michigan Power Station

Identification No.	PID	PIW	DD	DW	Unmodified DE1
Modifying Stone	Limestone	Limestone	Dolomite	Dolomite	-
Mode of Collection	Dry	Wet	Dry	Wet	
Chemical Properties,%					
SiO_2	30.85	19.39	30.81	23.34	49.10
Al_2O_3	13.70	7.98	12.54	9.03	16.25
Fe_2O_3	11.59	9.65	10.72	9.99	22.31
TiO_2	0.68	0.31	0.42	0.43	1.09
CaO	33.58	26.02	17.90	13.84	4.48
MgO	1.49	0.69	14.77	9.24	1.00
Na_2O	1.12	0.33	0.72	0.65	-
K_2O	0.71	0.62	0.99	0.83	-
SO_3	2.20	10.94	8.09	18.68	0.73
C	1.12	2.20	1.76	2.11	2.21
Moisture	0.00	Slurry	0.00	Slurry	0.00
Loss on Ignition	1.03	10.85	1.95	9.00	-
Water Soluble Fraction	22.11	22.52	20.39	21.08	2.51
Physical Properties					
Melting Properties,°F					
Initial Deformation Temp.	2071	2030	2246	2061	1702
Softening Temp., Spherical	2138	2316	2356	2237	2400
Ash Softening Temp.	2145	2336	2412	2246	2410
Fluid Temp.	2172	2381	2430	2260	2460
Median Particle Size, Microns	9.30	9.00	9.30	9.50	7.10

between the coal ash and lime constituents. However, the initial utilization potential tests did not indicate any beneficiation scheme would yield a relatively pure material from the coal ash fraction of modified flyash. Separation of the coal ash constituents would be more difficult after limestone or dolomite injection as a result of dilution of the fine flyash with equally fine lime, magnesia and sulfates of lime and magnesia. The results did indicate that the addition of limestone and dolomite to the boiler to fix sulfur had not altered the characteristic glassy, physically-agglomerated makeup of flyash when the stone was injected above the flame envelope as was the case at the St. Clair facility and in one test at St. Louis. The degree of reaction between limestone or dolomite when admixed with the coal prior to combustion has not been determined. Thermodynamic considerations indicate that the formation of calcium silicates are possible.(6) However, the test data indicated that modified flyash consists of the normal flyash resulting from coal combustion and calcined, partially sulfated limestone or dolomite in a thoroughly intermixed state. There was no indication of a change in chemical or physical bonding to any extent beyond simple electrostatic attraction.

Most results were obtained from samples of limestone and dolomite flyashes generated at Detroit Edison Company, St. Clair, Michigan because they were the first modified flyashes available in substantial quantities. The results obtained with the Detroit Edison modified flyashes revealed that certain separation and utilization schemes would be of little value due to physical or chemical limitations of the modified flyash.

MODIFIED FLYASH SAMPLES AND CHARACTERIZATION RESULTS

Modified flyashes used in this study were obtained from the following sources: (a) Detroit Edison Company, St. Clair, Michigan power plant; (b) Babcock and Wilcox Company research center, Alliance, Ohio; (c) Tennessee Valley Authority, Colbert, Alabama power plant and (d) Chevrolet Motor Division plant, St. Louis, Missouri. In addition to the modified flyash samples, samples of the flyash normally produced were also obtained for comparative purposes. Samples of the stones injected were also collected when possible. When stone samples could not be obtained, chemical analyses were requested.

Details concerning the development, collection and characteristics of the samples supplied by each source follow:

Detroit Edison Company, St. Clair, Michigan[7]

The work undertaken at the St. Clair, Michigan power station was a joint effort by Detroit Edison Company and Combustion Engineering, Inc. to field test the dolomite injection - wet collection sulfur oxide removal system under development by Combustion Engineering, Inc. In these tests only a small amount of the dust-laden stack gases were diverted to a wet scrubber so that both wet and dry collected modified flyashes were available. When the dolomite tests were completed a high purity limestone was tested. Thus, it was possible to obtain both wet and dry collected limestone and dolomite modified flyashes. The chemical and physical properties of these

TABLE 3

Chemical and Physical Properties of Modified Flyash and Normal Flyash Generated During Injection Tests at Tennessee Valley Authority Colbert, Alabama Power Station

Identification No.	DID2	DID3	Unmodified Ash*
	Sylacauga	Selma	-
Modifying Stone	Limestone	Limestone	-
Mode of Collection	Dry	Dry	-
Chemical Properties, %			
SiO_2	29.52	31.68	44.90
Al_2O_3	13.00	14.29	20.50
Fe_2O_3	14.85	15.97	16.90
TiO_2	0.53	0.56	-
CaO	22.55	24.94	6.10
MgO	1.56	1.49	1.10
Na_2O	0.59	0.77	0.30
K_2O	1.42	1.63	0.80
SO_3	3.73	1.95	-
C	0.88	0.91	-
Moisture	0.10	0.20	-
Loss on Ignition	2.00	1.30	-
Water Soluble Fraction	21.58	9.58	-
Physical Properties			
Melting Properties, °F			
Initial Deformation Temp.	1740	1730	-
Softening Temp., Spherical	2100	2120	-
Ash Softening Temp.	2120	2130	-
Fluid Temperature	2140	2140	-
Median Particle Size, Microns	3.80	4.40	-

---

*Analysis Obtained From Tennessee Valley Authority four modified flyashes and the flyash normally produced at St. Clair are shown in Table I. The sources and chemical analyses of the limestone and dolomite used in these tests are given in Table 2.

TABLE 2
Source and Chemical Composition of Stones Used In
Detroit Edison-Combustion Engineering Tests,
St. Clair, Michigan

Source	Type Stone	$\%SiO_2$	$\%R_2O_3$	$\%CaO$	$\%CaCO_3$	$\%MgO$	$\%MgCO_3$	Acid Insoluble
Drummond Island, Michigan	Dolomite	0.57	0.74	29.89	53.34	22.30	46.63	0.94
Presque Isle, Maine	Limestone	1.06	1.04	53.81	96.03	0.57	1.41	1.54

In these tests, the coal and stone was pulverized to approximately 95 percent passing 200 mesh. The crushed stone was injected through the top burner, oriented 30° above the horizontal, of a 325 megawatt Combustion Engineering twin furnace unit. In the initial tests, dolomite was fed into the boiler at a rate of 6.4 tons per hour (115 percent of the stoichiometric amount required to remove all sulfur oxides generated by the 3 percent sulfur content Ohio strip coal being burned). In the other series of tests, limestone was fed into the boiler in a similar manner but at a rate of approximately 10 tons per hour (180 percent of the stoichiometric requirement).

A combination of electrostatic and mechanical precipitators, rated to be 99.5 percent efficient, were used to collect the dry samples. The dry modified flyashes from each type of precipitator were admixed after collection. The wet scrubbed materials were obtained from the settling tank of the wet scrubbing circuit.

Tennessee Valley Authority, Colbert, Alabama[8]

These limestone modified flyashes were generated at the TVA Colbert, Alabama power station in separate periods of operation when different limestones were being tested. Analyses are shown in Table 3 for the modified flyashes and the flyash normally produced by TVA at the Colbert Station. The sources and chemical analyses of the limestones used in these tests by TVA are shown in Table 4.

TABLE 4
Source and Chemical Compositions of Limestones Used in Tests by TVA
Colbert, Alabama

Source	Type Stone	$\%SiO_2$	$\%R_2O_3$	$\%CaO$	$\%CaCO_3$	$\%MgO$	$\%MgCO_3$	$\%SO_3$
Sylacauga, Alabama	Limestone	2.10	0.40	54.00	96.43	0.72	1.51	0.04
Selma, Alabama	Limestone	12.50	6.00	44.30	79.11	0.60	1.26	0.90

TABLE 5

Chemical and Physical Properties of Modified Flyash and Normal Flyash Generated During Babcock and Wilcox, Inc. Tests at Alliance, Ohio Research Facility

Identification No.	PHS 42	PHS 45	PHS 46	PHS 47	Unmodified B22791
Modifying Stone	Dolomite	Dolomite	Dolomite	Dolomite	-
Mode of Collection	Dry	Dry	Dry	Dry	-
Chemical Properties, %					
SiO_2	23.80	17.29	19.02	15.00	43.41
Al_2O_3	10.54	7.80	7.55	7.08	23.60
Fe_2O_3	9.92	6.17	7.50	6.84	21.94
TiO_2	0.42	0.36	0.38	0.36	1.07
CaO	27.80	30.40	30.98	32.15	6.89
MgO	18.09	20.12	20.48	21.77	0.65
Na_2O	0.61	0.62	0.41	0.36	1.65
K_2O	0.68	0.69	0.79	0.69	0.78
SO_3	4.40	5.56	5.55	5.92	1.11
C	3.66	3.96	3.47	3.42	1.01
Moisture	0.40	0.50	0.40	0.40	0.70
Loss On Ignition	11.77	12.06	11.10	11.17	1.68
Water Soluble Fraction	10.25	12.24	11.53	12.40	7.90
Physical Properties					
Melting Properties, ^{o}F					
Initial Deformation Temp.	1790	1780	1800	1790	1760
Softening Temp., Spherical	2520	2610	2660	2650	1990
Ash Softening Temp.	2530	2613	2680	2660	2030
Fluid Temp.	2550	2632	2685	2670	2050
Median Particle Size, Microns	8.30	7.80	7.10	8.00	7.80

In these tests, the particle size of limestone injected ranged from 70 percent passing 200 mesh to 95 percent passing 325 mesh. Limestone was injected into the boiler through all sixteen burners by pre-mixing with the coal in proportions approximately equal to 67 percent of the stoichiometric requirement for the 6 percent sulfur content coal being burned. These dry-collected limestone modified flyashes were obtained from standard mechanical cyclone dust collectors which had been designed to remove approximately 70 percent of the particulate matter in the stack gases. In dust collectors of this type, the finer size fractions generally escape to the atmosphere. Thus, the smallest size fractions of modified flyash were not recovered.

Babcock and Wilcox Company, Alliance, Ohio[9]

The modified flyashes generated by Babcock and Wilcox (B&W) were produced during additive tests to determine the effectiveness of raw, hydrated and calcined limestones and dolomites in reducing sulfur dioxide emissions and to determine their effect on boiler slagging, ash viscosity and ash fusion properties. The modified flyashes characterized were produced in a pilot plant furnace designed to burn from 3 to 20 pounds of coal per hour under controlled conditions. Chemical and physical analysis of the modified flyashes and the parent coal ash characterized are shown in Table 5.

The source and chemical analysis of the dolomite used in these tests is described in Table 6.

TABLE 6
Source and Chemical Composition of Limestone
Used in Babcock & Wilcox Company Tests,
Alliance, Ohio

Source	Type Stone	%SiO_2	%R_2O_3	%CaO	%$CaCO_3$	%MgO	%$MgCO_3$	Loss On Ignition
Charles P. Fizer Co. Gibsonburg, Ohio	#10 Glasshouse Dolomite	0.004	0.00	28.25	50.98	23.00	48.30	47.50

In these tests, dolomite was pulverized to 90 percent passing 200 mesh. The dolomite was injected into the B & W pilot plant furnace 2 3/4 feet below the furnace outlet at a rate amounting to 110 percent of the stoichiometric requirement for the 4.3 percent sulfur content of the parent B-22791 coal being burned. The dry collected ash samples were obtained from a cyclone separator at the pilot plant boiler outlet.

Chevrolet Motor Division Plant, St. Louis, Missouri

The injection tests undertaken by Chevrolet Motor Division at their St. Louis assembly plant were performed in a small B & W boiler having a capacity of two tons of coal per hour. Preground commercially available dolomite was tested both by intermixing and by injection above the flame envelope. Physical and chemical characteristics of the resultant modified flyashes and the flyash normally produced by this boiler are shown in Table 7. The CM modified flyash was produced by premixing the dolomite and coal while the CI material was produced by injecting the material above the flame envelope. The source and chemical analysis of the dolomite used is shown in Table 8.

TABLE 7

Chemical and Physical Properties of Modified Flyash and Normal Flyash Generated During Tests at Chevrolet Motor Division, St. Louis Plant

Identification No.	CM(Premixed)	CI(Injected)	CU(Unmodified)
Modifying Stone	Dolomite	Dolomite	-
Mode of Collection	Dry	Dry	-
Chemical Properties, %			
SiO_2	35.90	33.10	48.40
Al_2O_3	14.40	11.80	18.40
Fe_2O_3	7.76	7.18	13.60
TiO_2	0.71	0.65	1.10
CaO	19.18	17.92	5.18
MgO	12.61	11.45	1.66
Na_2O	0.34	0.46	0.58
K_2O	0.72	0.72	1.30
SO_3	8.05	6.95	3.18
C	3.29	5.64	9.67
Moisture	0.24	0.26	0.30
Loss On Ignition	3.79	8.34	11.58
Physical Properties			
Melting Properties, °F			
Initial Deformation Temp.	1870	1720	1890
Softening Temp., Spherical	2260	2250	2250
Ash Softening Temp.	2270	2270	2260
Fluid Temp.	2300	2280	2270

TABLE 8
Source and Chemical Composition of Dolomite Used In
Tests at Chevrolet Motor Division Plant,
St. Louis, Missouri

Source	$\%SiO_2$	$\%R_2O_3$	$\%CaO$	$\%CaCO_3$	$\%MgO$	$\%MgCO_3$
Birmingham, Alabama	3.61	1.65	29.76	53.11	21.27	44.47

In these tests, the dolomite, vended as "Dolcito", was injected into the B&W pulverized coal intergal furnace type boiler at a rate of 200 percent of the stoichiometric amount required. The dolomite had been pulverized by the supplier to 76 percent passing 230 mesh and 4.4 percent passing 325 mesh. The coal burned during the tests contained 3 1/2 percent sulfur and was obtained from the River King No. 2 mine of Peabody Coal Company and the Sparta Mine of Bell and Zoller Company. The coal was fed to a B&W Type E pulverizer in a ratio of 60 percent River King to 40 percent Sparta where it was pulverized to 70 percent passing 200 mesh prior to combustion. The dry modified flyash was collected in an electrostatic precipitator rated to be approximately 99 percent efficient.

In the initial test, dolomite was admixed with the coal by adding 50 pounds of dolomite every three minutes through the exit port of the weigh feeder. A 45 minute delay occurred between the time dolomite was first added and a stable reduction of sulfur dioxide occurred. After the stable reduction occurred the test was continued for three hours.

In the second test dolomite was injected from a spider system specifically designed to permit the dolomite to be uniformly sprayed, via six nozzles, into the boiler above the flame envelope at an angle of approximately 45 degrees above the horizontal. This test was also of three hours duration, however, a reduction of sulfur dioxide in the stack gases occurred almost immediately.

Characterization Results

By contrasting the data for modified and normal flyashes obtained by each of the four testing facilities, the degree of modification of the physical and chemical characteristics resulting from the injection of limestone or dolomite can be seen. Levels of silica, alumina and iron oxide, the major constituents of normal flyash, are decreased while the lime and magnesia content is greatly increased. The injection of limestone and dolomite also resulted in expected increases in the ash fusion temperatures since the ash became more refractory with increased levels of lime and/or magnesia above about 30 percent.(10) The amount of water soluble constituents was also increased when limestone or dolomite was injected with the result that the standard ASTM test for soluble constituents had to be modified by reducing the modified flyash sample size so that the insoluble residue could be dried to a constant weight. The median particle size of modified flyashes was approximately the same as the normal unmodified flyashes, indicating that the degree of grinding of the stone is approximately the same as that of coal when the coal mills are used for grinding.

Initially, small samples of the wet collected materials obtained from Detroit Edison set up cementitously in a few days. This setting was greatly retarded for about six months by maintaining a layer of water over the sample. In most instances it was necessary to dry the wet collected samples prior to characterization or testing.

MODIFIED FLYASH UTILIZATION POTENTIAL

As a result of the extensive physical separations and utilization tests on the whole and sized fractions of modified flyash, several feasible methods of utilization were determined. The potential for profitable utilization has been divided into three categories. The utilization method having the greatest potential is the conceptual Emission Control Minerals Complex (ECMC) because it makes use of all fractions of modified flyash and could lower operating costs for stone injection. Of lesser importance are utilization methods of lower potential because of limited markets or chemical and physical limitations of modified flyash. Finally, some beneficiation procedures and utilization methods were studied which had little potential due to the physical and chemical makeup of modified flyash.

Utilization Method of Good Potential - The ECMC Process For Total Modified Flyash Utilization Through Multiple Beneficiation

The ECMC process understudy incorporates the most promising utilization methods found during the course of contract work. This preliminary plan has the aim of utilizing all fractions of modified flyash through (a) recovery of lime for reinjection, (b) mineral wool production and (c) sulfur recovery. A categoric description of the three main products from the two processes which make up the conceptual plan follows.

Recovery of lime The carbonation of modified flyash-water slurry followed by agglomerate flotation has yielded concentrates containing 58.19 percent lime from DID2 modified flyash. This amounts to more than a 2 1/2 fold enrichment over the original feed lime content of 22.55 percent and results in a product that contains more lime than the highest quality limestone. Carbonation, the introduction of carbon dioxide into the modified flyash - water slurry, decreases the amount of undesirable water soluble calcium as a result of the formation of relatively insoluble calcium carbonate. Carbonation also causes the pH to be lowered providing a means to condition the slurry and facilitate agglomerate flotation. Agglomerate flotation, a highly specialized mineral preparation process that is more amenable than froth flotation to very fine slime-like materials such as modified flyash, is the intensive mixing of the carbonated slurry and emulsified organic chemicals with the result that the ultra fine calcium carbonate particles cluster together and are levitated to the surface of the slurry by mechanically induced air bubbles where the agglomerated particles are removed. The employment of carbonation to condition the slurry was additionally supported by zeta potential (a measure of the surface charge on a particle suspended in a liquid) measurements which indicated that for the best separation it would be necessary to regulate the slurry pH in order to favorably adjust and maximize the differences between the surface charges of the siliceous flyash and lime particles contained in the slurry.

It has been found that the possible formation of extremely soluble calcium bicarbonate by excess carbonation is not a problem. Bicarbonate formation occurs by the reaction:

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2$$

when excess carbon dioxide is added. Should this be a problem with other modified flyashes, it could be surmounted by heating the slurry. Heating the slurry also would have the advantage of lowering the solubility of all calcium compounds likely to be present which should (a) lower the amount of soluble materials to be separated, (b) shorten the conditioning time and (c) more rapidly activate the fraction to be floated.

The primary aim of the conceptual plan is to recover lime for reinjection. The present agglomerate flotation separation used for this purpose consists of (a) vigorously agitating or grinding the one part modified flyash to two part water slurry as a means of exposing new surfaces on the lime and silica particles; (b) carbonating the slurry to lower the pH to seven; (c) adding modifiers such as ferric or cupric chloride to promote dispersion of lime from silica particles during conditioning and agglomerate flotation; (d) agglomeration by the addition of anionic oil-water emulsions and conditioning in flotation cells at slow rotor speeds; and (e) agglomerate flotation separation by admitting air to the cell to levitate the lime rich fraction of modified flyash to the surface for mechanical removal at the desired pH.

The best emulsion used to date consisted of 50 percent water, 25 percent fuel oil, 22 1/2 percent tall oil and 2 1/2 percent sulfonate surfactant for froth production. Certain types of tall oil also require the addition of trace amounts of barium or calcium chloride, to stabilize the emulsion. Emulsion addition rates are equivalent to about 112.6 pounds per ton of modified flyash on a water free basis. This amounts to a cost of approximately $3.56 per ton. While no attempt has been made to recover the emulsion, recovery is a common operation in agglomerate flotation circuits and should result in reuse of more than 80 percent of the oils and surfactant.

There would be a substantial saving in limestone costs if lime could be commercially recovered as calcium carbonate by agglomerate flotation. Moreover, the calcium carbonate recovered would be in a finely divided (10 microns or less), and highly active state and have an adsorption capacity greater than limestone. In addition, reagents such as iron compounds, etc could be added during recovery to enhance the capture of sulfur oxides on reinjection which could further reduce the amount of limestone required. In effect, the calcium carbonate recovered for reinjection could be custom tailored to promote uniformity of the reinjected material thereby enhancing sulfur fixation.

Preliminary cost estimates indicate that, based upon 80 percent recovery of injected lime and reinjection of an 80 percent lime product, a relative operating cost reduction of about 42 percent might be realized over the cost of once through limestone injection. These relative cost figures are based on economic assumptions and feasibility data of limestone injection made or obtained by other NAPCA contractors (11,12) and include all cost effects, both direct and indirect, including equipment write-off.

Production of mineral wool Extensive tests on a pilot plant scale have shown that mineral wool of high quality can be produced from modified flyashes. A summary of the qualitative and quantitative data obtained on mineral wools produced from the various modified flyashes is given in Table 9. For comparative purposes the characteristics of mineral wool produced from normal unmodified B-22791 are also included. From Table 9 it can be seen that wools were produced that varied in color from brown to grey and contained attached shot ranging from 20 to 40 percent of the weight of the uncleaned product. Shot is the result of incomplete fiber formation when the molten material

TABLE 9

MODIFIED FLYASH MINERAL WOOL
DESCRIPTION AND PRODUCTION TESTS RESULTS

SAMPLE	DD	DW	PID	PIW	DID2	DID3	Unmodified B22791
Wool Description	Good Fiber With Little Attached Shot, Light Grey to White	Small Fiber	Light Brown Fluffy Wool With Little Shot Attached Resilient Fiber	Average Fiber Diameter of 10-15 Microns With Lots of Unattached Fine Shot	Grey Fibers, Moderate Amount of Shot	Average Fiber	Unsatisfactory
Shot Content of Wool, %	26.0	39.3	27.0	24.7	24.7	20.0	63.3
Humidity Test, % Absorption		0.1		0.3	0.0	0.0	Not Tested
Corrosion Test	Minimal Corrosion, No Deep Etching	Very Light Surface Rust, Much Better Resistance Than Test Blank	Minimal, Less Than Blank, No Deep Etching	Minimal, Much Less Than Test Strips	Very Light Surface Rust, Some Chemical Etching, Less Than 5 Percent	Some Chemical Etching, Less Than 5 Percent	Not Tested
Flame Test	Nonflamable	Nonflamable	Nonflamable	Nonflamable	Nonflamable	Nonflamable	Nonflamable
Comments	High Yield Smoke And Sulfur Smell Present During Production Run. Long Pouring Range	Wool Not As Good As Other Flyashes. Molten Slag Stream Tends To Break Up And Does Not Pour Well. Smoke and Sulfur Present During Production Run	Very Fluid Melt At Low Temp. With Good Pouring Range	Smoky With Sulfur Smell During Production Run. Melt Tended To Be Very Fluid	Very Good Wool	Low Yield	Requires More Heat To Melt
Acid to Base Ratio	1.32	1.40	1.27	1.00	1.22	1.92	9.03

is poured from the furnace and simultaneously blasted with steam or compressed air. The amount of shot present in a mineral wool is a function of the melt viscosity and is commonly removed during cleaning by raking. It has been indicated that cleaning mineral wools produced from modified flyash would be similar to other mineral wool cleaning operations and would present no difficulty.

The melts listed in Table 9 were very fluid at temperatures of approximately 2500°F. This increased fluidity permitted longer pouring and blowing time at equivalent temperatures or conversely, equivalent pouring time at lower temperatures as compared with the normal unmodified flyash. Data in Table 9 for such service tests as humidity, corrosion and flame resistance indicate that mineral wools produced from modified flyash were as good or better than commercial rock and slag wools.

The superiority of modified flyash mineral wools over mineral wools produced from normal flyash appeared to result from the addition of limestone or dolomite to the boiler to capture sulfur. Limestone or dolomite addition had the beneficial effect of altering the ash acid to base ratio (percent silica plus percent alumina)/(percent lime plus percent magnesia) from approximately ten to the generally acceptable mineral wool production range of 0.85 to 1.25. This alteration is evident in Table 9 where the normal flyash having an acid to base ratio of 9.03 produced unsatisfactory wool while modified flyashes with acid to base ratios within or near the 0.85 to 1.25 range produced acceptable wools.

The addition of fluxes to normal flyash to adjust the acid to base ratio was not successful because the materials could not be intimately mixed to prevent spot slagging or "hot spots" in the kiln. In modified flyash the alkaline fluxes and coal ash constituents are intimately mixed in the boiler with the result that a uniform low viscosity is obtained at about 2500°F as compared to 3000°F or higher for normal flyash and coal slags.

Manufacturing cost data are presently unavailable on modified flyash mineral wool. Indications are that conventional rock or slag mineral wool processing equipment would be suitable and that production costs should be lower because of the low heat requirements to produce fluidity and the elimination of expensive flux additions.

Recovery of sulfur derivatives It was found that the sulfates such as calcium and magnesium sulfate present in modified flyash can be thermally decomposed to yield a sulfur-rich gas for further processing. The attractive possiblity of recovering sulfur from modified flyashes first became apparent when it was observed upon heating these materials in mineral wool production tests that malodorous sulfur oxide gases were evolved from the melt prior to pouring. The evolution of sulfur gases was considered to be anomalous because the mineral wool production kiln normally operates under oxidizing conditions. Moreover, the calculated equilibrium constant (2.4×10^{-4}) and heat of reduction for thermal decomposition of calcium sulfate at 2200°F (1.96×10^{5} Btu per pound mole) are unfavorable. However, the heat of reduction for calcium sulfate decreases with increasing temperatures thus favoring decomposition at higher temperatures (13,14).

Bench scale tests, designed to determine what reactions were occurring during heating, utilizing a tube furnace and infrared spectrometer showed

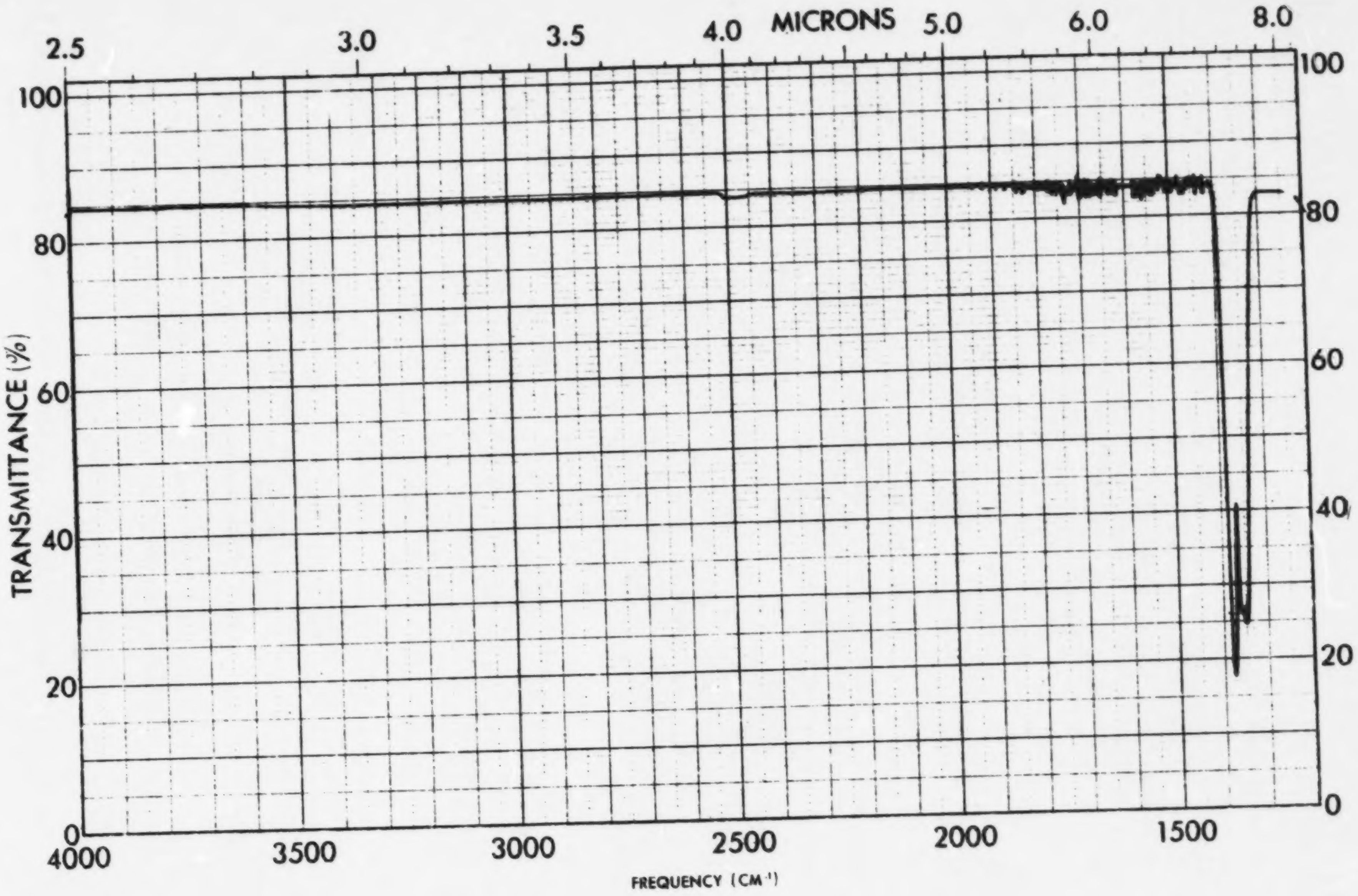


FIGURE 1

INFRARED SPECTRA OF GASES EVOLVED FROM MODIFIED FLYASH NUMBER D1D2 UNDER OXIDIZING CONDITIONS AT 2100°F, 4000 to 1200 cm^{-1}

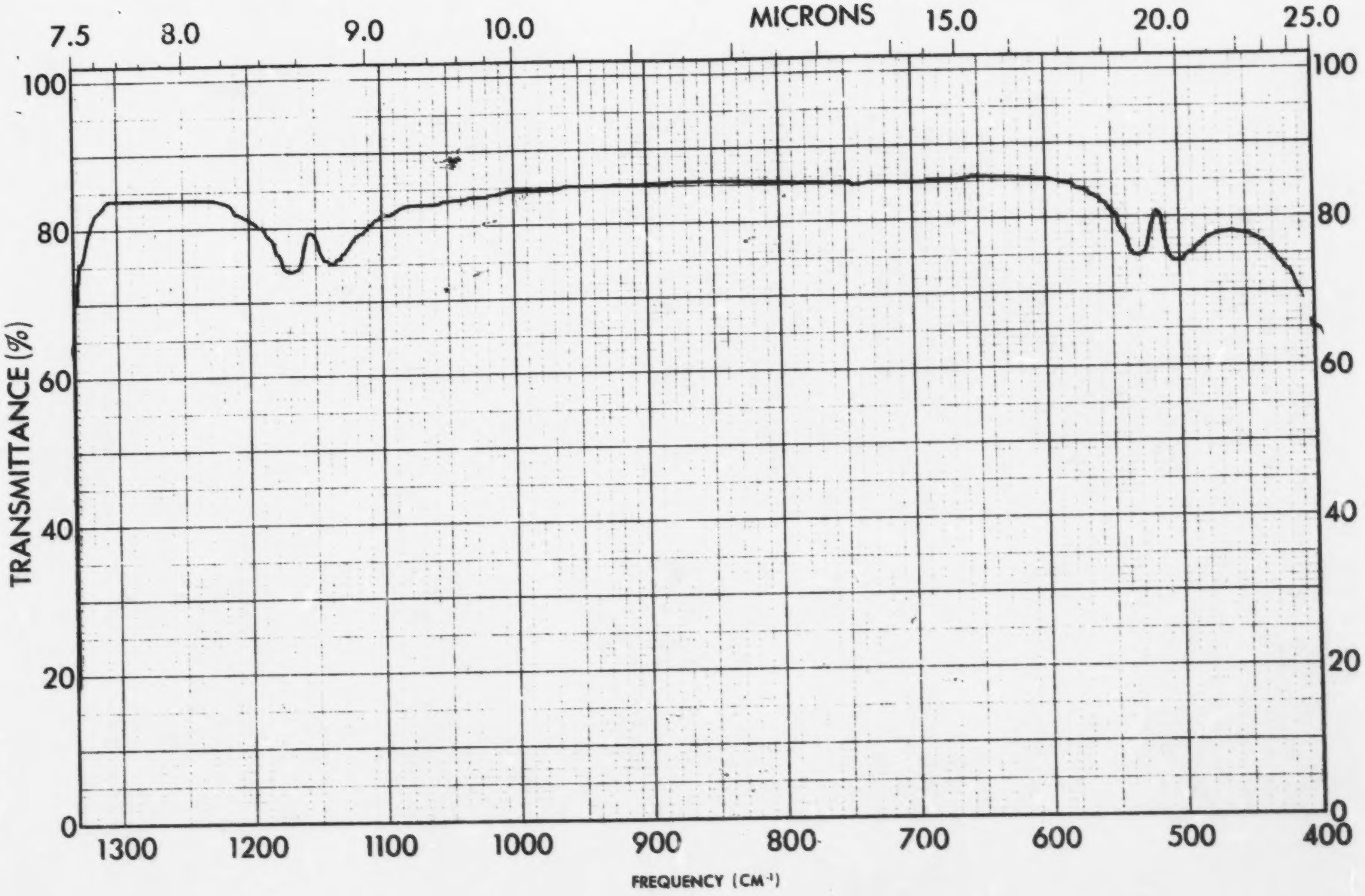


FIGURE 1a

INFRARED SPECTRA OF GASES EVOLVED FROM MODIFIED FLYASH NUMBER D1D2 UNDER OXIDIZING CONDITIONS AT 2100°F, 1330 to 400 cm^{-1}

that sulfur dioxide was the only gas evolved under oxidizing conditions in the 2000 to 2100°F temperature range. This is shown in Figure 1 and 1a which are the infrared spectra of the gases evolved from modified flyash DID2 (TVA) at 2100°F. The characteristic absorption bands of sulfur dioxide at 1375, 1350, 1167 and 1138 wave numbers are evident. The reduction of absorption intensity in the 2500 wave number region is due to the dilution of the sample as a result of the tube furnace being swept with air (15). Additional tests with the tube furnace and a titration apparatus showed that dihydrated calcium sulfate when heated to 2100°F under oxidizing conditions gave off 91 percent of the sulfur present and indicated that decomposition approached quantitative yields. In a similar test modified flyash PID gave off 95 percent of the sulfur present.

There are three advantages to be gained if the sulfur recovery phase of the ECMC process could be placed into practice. First, the effluent gases from mineral wool kilns would have a higher concentration of sulfur gases than normally found in coal fired power station stack gases due to increased amounts of sulfur present in modified flyash. This concentration factor would also be enhanced by the fact that the sulfurous gases are given off over a narrow range of temperature. Secondly, these sulfur-rich stack gases should be relatively free of troublesome nitrous oxides and solid particulate matter commonly found in stack gases during coal combustion. Finally, less fuel would be required for producing sulfur oxide under oxidizing conditions than under reducing conditions.

The ECMC process Work to date on the ECMC process has been of a preliminary nature. The ECMC process in its present state is envisioned as outlined in Figure 2. Modified flyash would be transferred from the power plant precipitators (1) to a conditioning tank (3) for the purpose of mixing modified flyash and heated water in a uniform slurry. Simultaneously, stack gases rich in carbon dioxide would be diverted from the stack (2) to the conditioning tank (3) for the purpose of further heating the slurry and carbonating the unreacted lime and magnesia materials present to their corresponding carbonate form. Carbonation by the injection of the carbon dioxide containing stack gases could result in the following threefold advantages that would not be possible otherwise:

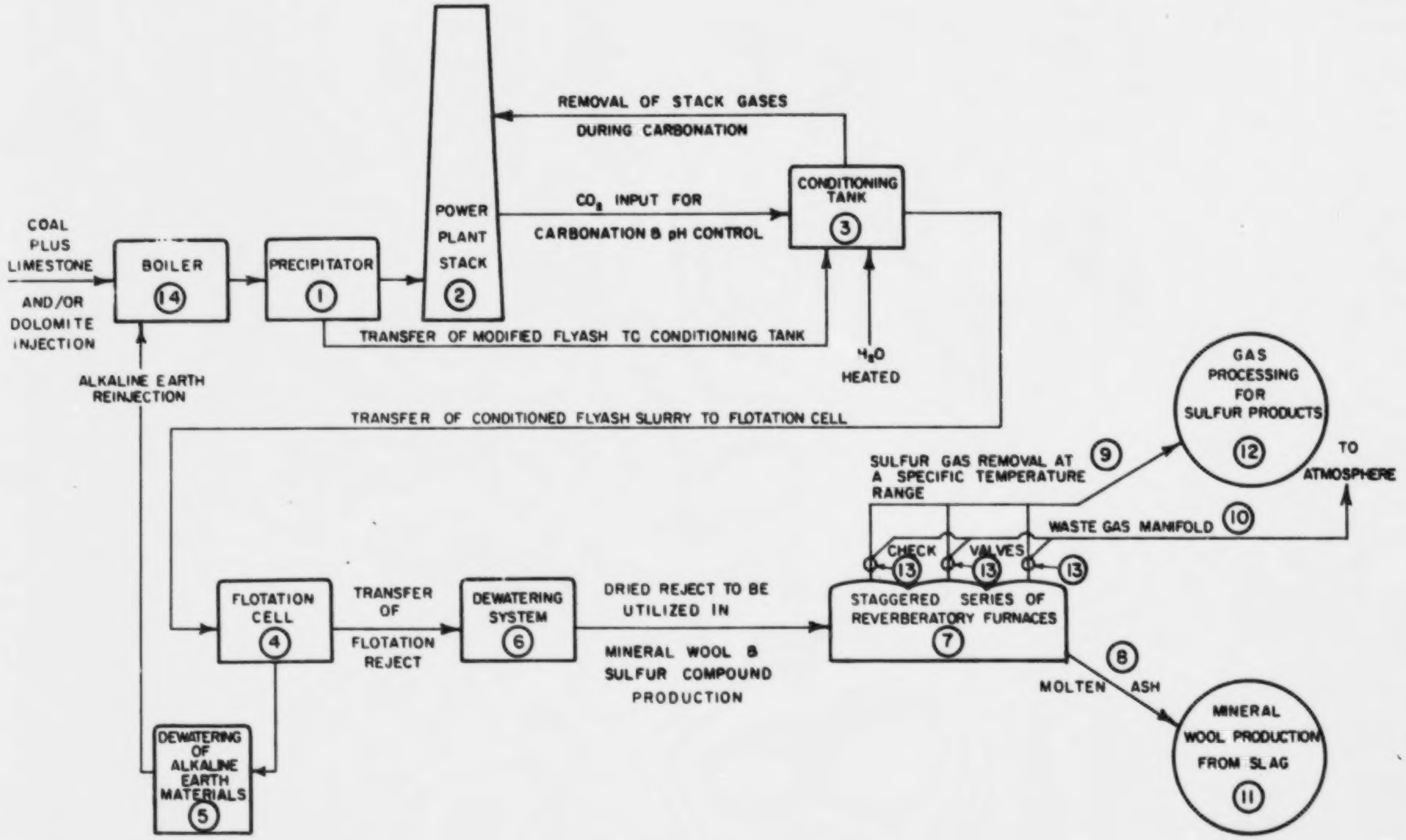
a. The hot stack gases would partially heat the slurry thereby reducing the water heating requirements.
b. Heated slurries could decrease the amount of unreacted lime and magnesia initially taken into solution, therefore, less carbon dioxide would be required to remove soluble lime and magnesia and adjust the pH for optimum agglomerate flotation separation.
c. Carbonated lime and magnesia responds more readiliy to agglomerate flotation.

In the event that unreacted sulfur gases entered the conditioning tank and formed more calcium and magnesium sulfates, wet collection may remove the additional sulfur containing materials for subsequent processing.

After carbonation, modified flyash slurry would be transferred to a flotation cell (4) for recovery of the calcium carbonate-rich fraction by agglomerate flotation. The calcium carbonate-rich fraction would be dewatered (5) for reinjection into the boiler (14) while agglomerate flotation rejects, containing lesser amounts of unreacted lime and magnesia but containing more of the reacted lime and magnesia, would be dewatered (6) prior to drying.

Figure 2

THE EMISSION CONTROL MINERALS COMPLEX (ECMC) PROCESS


COAL
PLUS
LIMESTONE
AND/OR
DOLOMITE
INJECTION
BOILER
14
PRECIPITATOR
1
POWER
PLANT
STACK
2
REMOVAL OF STACK GASES
DURING CARBONATION
CO₂ INPUT FOR
CARBONATION & pH CONTROL
CONDITIONING
TANK
3
TRANSFER OF MODIFIED FLYASH TO CONDITIONING TANK
H₂O
HEATED
ALKALINE EARTH
REINJECTION
TRANSFER OF CONDITIONED FLYASH SLURRY TO FLOTATION CELL
GAS
PROCESSING
FOR
SULFUR PRODUCTS
12
TO
ATMOSPHERE
SULFUR GAS REMOVAL AT
A SPECIFIC TEMPERATURE
RANGE
9
WASTE GAS MANIFOLD
10
CHECK
VALVES
13
13
13
FLOTATION
CELL
4
TRANSFER
OF
FLOTATION
REJECT
DEWATERING
SYSTEM
6
DRIED REJECT TO BE
UTILIZED IN
MINERAL WOOL &
SULFUR COMPOUND
PRODUCTION
STAGGERED SERIES OF
REVERBERATORY FURNACES
7
8
MOLTEN
ASH
MINERAL
WOOL PRODUCTION
FROM SLAG
11
DEWATERING
OF
ALKALINE
EARTH
MATERIALS
5

The purpose of a staggered firing system would be to yield a relatively steady supply of molten material (8) and clean, sulfur-rich gas (9) from furnaces designed for batch operations. This molten material could be tapped and blown into mineral wool insulating fibers (11) when the temperature is sufficient to produce a viscosity of approximately 10 poise or less.

The calcium and magnesium sulfates and other sulfur components present in modified flyash would break down in an oxidizing atmosphere to form sulfur dioxide gas at a temperature of approximately 2000-2500°F. Because reverberatory furnaces would be used, the gases (9) might be selectively withdrawn, by the use of check valves (13) over a narrow temperature range (nominally 1800-2500°F) in a more concentrated and clean form than is usually present in common flue gases. These enriched sulfur containing gases could then be processed into useful sulfur derivatives (12) such as liquid sulfur dioxide, sulfuric acid, sulfur, etc., using common processing methods. The remaining hot gas emissions could be used to supply thermal energy, either directly or by the use of heat exchangers, for further processing steps before being passed to the atmosphere (10).

Utilization Methods Of Lesser Potential

The following methods of utilization of modified flyash without prior beneficiation of any sort were determined to have promise because of the unique characteristic of this material for a particular application. However, other physical, chemical or market limitations would limit utilization of large quantities of modified flyash.

Acid mine drainage neutralization (16) It has been found that limestone modified flyash can be used in place of lime as a neutralizer for acid mine drainage. The salient developments in this phase of research are that limestone modified flyash decreased sludge settling time from three hours when using lime to five minutes when using modified flyash, increases filtration from very little in 20 minutes to near complete dewatering in one to three minutes, increases the chances for waste utilization because the products can be successfully dewatered for further processing. However, the amount of modified flyash needed to neutralize acid mine drainage is as much as 10 to 100 times greater than the lime requirement. These preceding observations suggest that lime should probably continue to be considered for acid mine water neutralization but that admixed modified or unmodified flyash may find application as a settling agent to enhance solid-liquid separation and utilization.

Concrete admixture Extensive investigations involving chemical analysis, pozzolanic activity with lime and cement, compressive strength, soundness, alkali reactivity and mortar expansion tests led to the conclusion that modified flyash could find application in some instances as a concrete admixture. The results of pozzolanic activity tests are given in Table 10. The chemical and physical requirements of flyash for use as a concrete admixture set forth in ASTM C-350 are also given in Table 10 for comparative purposes. As indicated in Table 10, none of the modified flyashes investigated met the ASTM C-350 chemical requirements. However, all the modified flyashes met the physical requirement for fineness, mortar cube compressive strength and the 28 day lime-flyash pozzolanic strength test. The attainment of other physical requirements varied with each modified flyash and suggests that each modified flyash should be tested empirically to determine the best proportions to use as well as its acceptability for a particular job application.

TABLE 10

POZZOLANIC ACTIVITY CHARACTERIZATION TEST RESULTS FOR MODIFIED FLYASHES

Chemical Requirements	ASTM C-350 Requirements	PID	PIW	DD	DW
Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3) minimum, percent	70.00	56.63	37.02	54.07	42.26
Magnesium oxide (MgO), maximum percent	5.0	1.08	0.69	14.77	9.24
Sulfur trioxide (SO_3), maximum percent	5.0	4.13	11.80	7.57	18.43
Moisture content, maximum percent	3.0	0.00	slurry	0.00	slurry
Loss on ignition, maximum percent	12.0	1.03	10.85	1.95	9.00
Available alkalies as Na_2O, maximum percent	1.5	1.71	0.85	1.55	1.35
Physical Requirements					
Fineness					
Mean particle diameter, microns, maximum	9.0	9.3	9.0	9.3	9.5
Compressive strength of mortar cubes					
Percent of control at 7 days, minimum	100	136	139	157	134
Percent of control at 28 days, minimum	100	138	134	157	130
Water requirements maximum percentage of control	105	97.4	122.6	99.1	114.8
Soundness					
Autoclave expansion of mortar bars, maximum percent	0.5	+5.07	-0.04	+0.24	0.00
Pozzolanic activity index:					
With Portland cement, at 28 days minimum, percentage of control	85	72.3	78.3	118.9	80.8
With lime, at 7 days, PSI	800	820	150	890	200
Lime-flyash pozzolanic strength:					
7 day strength, PSI	600	1580	360	1240	610
28 day strength, PSI	600	1850	630	1700	630
Uniformity Requirements					
Air entrainment in mortar, amount of air entraining resin required to produce air content of 18± 3 percent, milliliters	-	0.5688	0.763	0.9467	0.6667
Bulk density					
Lime-flyash mixtures	None	117	105	117	107

Cement Kiln Raw Material The utilization of modified flyash was also investigated as a possible raw material in the production of portland cement. A comparison of the chemical analysis of cement kiln feeds with modified flyash chemical analysis indicated that limestone modified flyash could supply a portion of both the argillaceous and calcareous components of the kiln feed without detriment to the quality of the resultant portland cement. Dolomite modified flyashes could not be used since a five percent maximum magnesia content exists for all types of portland cement.(17)

The inclusion of limestone modified flyash could have an economic advantage over present materials in that preparatory grinding would not be required. However, there could be a limitation on the amount of limestone modified flyash containing large amounts of iron (ie near stoichiometric additions of limestone) that could be admixed because of a U.S. Government limit of six percent ferric oxide on Types I through IV portland cement used in Federal jobs.(18) There is also a limitation on the amount of sulfur trioxide in the final product (2 1/2 or 3 percent) depending on the tricalcium aluminate content of the final Type I portland cement product. However, in view of sulfur dioxide evolution from modified flyash under oxidizing conditions in mineral wool and related tests, excessive sulfur should not be a problem.

The above chemical limits on portland cement manufacture from limestone modified flyash could most probably be overcome by blending with conventional cement raw materials. However, the major problem to be encountered in utilizing this material lies in the current overcapacity in the portland cement industry.(19) It appears unlikely that an additional supply of portland cement could be economically marketed in an industry that utilized only 74 percent of its rated capacity in 1967 as a result of overexpansion.

It may be possible to make cement manufacture economically more attractive by recovering sulfur gases from modified flyash in processes similar to the ICI-Billingham process. In this method, portland cement is produced and the high kiln temperatures cause the evolution of sulfur dioxide for by-product sulfuric acid production when a section of the cement kiln is operated under reducing conditions.(11) Numerous patents have been obtained for related processes for producing portland cement and by-product sulfur from gypsum.(20) While it appears that modified flyash might be successfully utilized in the ICI-Billingham or related processes, no published research results on this subject are available.

Another possibility considered in the area of cement manufacture was hydraulic cement.(17) However, a review of the chemical properties of modified flyashes indicated that they contained excessive amounts of argillaceous materials and could not be expected to produce high strength cements without further lime additions.

Soil stabilization The large amounts of lime present in modified flyash could make this material an excellent soil stabilizer without the admixture of additional lime to the flyash-soil mix. The stabilization of soils with lime and flyash has been practical as a means of modifying soil texture, stabilizing plastic clayey soil, decreasing soil plasticity and increasing friability, maintaining constant volume and imparting strength through pozzolanic action between the lime, flyash and soil.(21) Optimum proportions of lime and flyash have not been determined for stabilizing soils because of the wide variety of soils and flyashes and the interdependence of soil, lime and flyash components. The ratio of lime to flyash required to stabilize different textured soils ranges from 1:9 to 1:2. The ratio of lime or lime and magnesia added or reinjected to the coal ash constituents of modified flyash ranges from 1:2.2 to 1:7.4. Thus, the lime to flyash ratio requirement is met with modified flyashes and the only soil stabilization problem expected would be one of determining if the available modified flyash could be used with a particular type of soil. Moreover, an advantage might be gained by using wet collected materials in some instances because dusting problems during application would be eliminated; however, it would be necessary to apply the material before cementitious setting occurred.

Soil amendment Greenhouse tests(22) with dolomite modified flyash DD indicated that this material, and modified flyash in general, should have potential as a soil amendment and acidic soil neutralizer. A summary of these tests is shown in Table 11.

TABLE 11
Summary of Greenhouse Tests With Modified, Lignite and Bituminous Flyash

Flyash	Application Rate, TPA	Fescue Germination	Fescue Survival Rate, %	Yield Per Seed	Fescue Yield, Grams
Dolomite Modified DD	15	92	85	.22	18.4
Montana-Dakota Lignite	25	87	84	.23	19.5
Fergus Mine, Minn. Lignite	25	82	82	.20	16.1
Fort Martin, W.Va. Bituminous	100	21	18	.20	3.7
Control	0	61	56	.03	1.8

In these tests acid spoil from a recently leveled strip mine having a pH of 2.8 was admixed with flyash to neutralize the soil at pH 7.5. Duplicate mixtures of each flyash soil combination were treated with the equivalent of 1000 tons per acre (TPA) of 10-10-10 granulated fertilizer and seeded with 100 Kentucky fescue seeds and 25 birdsfoot trefoil seeds. Moisture was maintained at field capacity for each mixture and top and root yields determined after 61 days. Trefoil germination and survival was low and was not included in Table 11.

The data of Table 11 indicates that modified flyash DD neutralized the soil at significantly lower application rates than lignite flyash and yet had the best germination and survival rates. Yields were good at 18.4 grams and second only to the Montana-Dakota utilities lignite. Chemical analysis of the lignites are not available so that comparison of lime content cannot be made. Undoubtedly, however, a correlation between the lime content of a flyash and the amount required to neutralize a soil exists. For example, approximately 8 TPA of finely ground limestone are required to neutralize this spoil whereas 15 TPA of modified flyash DD, which is about half dolomite, were required.

The greenhouse tests were of a preliminary nature and further definitive tests would be required with different modified flyashes before the true potential of this material as a soil amendment can be assessed. Under the conditions of these tests it is indicated that high calcium ashes, regardless of the source of calcium, are extremely beneficial to plant growth and yield. Therefore, all modified flyashes, regardless of the mode of collection or type of stone injected should be of value. First, modified flyash would supply sulfur which agricultural limestone or lime would not. Secondly, because of the increased rates of addition, it could be used to adjust the soil from a sandy or clayey form to almost a pure loam which is ideal for plant growth. Better root nodulation has been obtained in flyash admixed soils which leads to the conversion of nitrogen to nitrogenous compounds. Finally, modified flyash would supply trace elements not normally available in amendments or fertilizer and yet would not be present in sufficient quantities to poison the plant, as is the case with normal unmodified flyashes.

An obvious detriment to the utilization of modified flyash as a soil amendment would be transportation of large quantities required to neutralize soil. Agricultural limestone is available in most areas at about $1.00 per ton F.O.B. plant. Therefore, transportation of the equivalent amounts of modified flyash, about twice the weight, could not exceed the low cost plus transportation charges for agricultrual limestone.

Beneficiation Procedures and Utilization Methods of Little Potential

The following beneficiation and utilization methods were found to be of little value as a result of the physical and chemical makeup of modified flyash.

Sizing Conventional wet and dry sieving, ultrasonic sieving and air classification sizing tests were undertaken in an effort to separate fractions of modified flyash having potential commercial value. The coarse sizes of limestone modified flyashes showed increased lime percentages while the fine sizes of dolomite modified flyash showed increased percentages of lime. Magnesia was also concentrated in the fine sizes of the dolomite modified material. Sulfur appears to be concentrated in the finer sizes of both materials. However, more than 75 percent of these materials passed through a 400 mesh sieve with the result that little actual beneficiation of the total product was obtained. Attempts were made to separate the minus 325 mesh fractions by ultrasonic sieving and air classification to determine if (a) products of commercial value could be obtained by size separation of the very fine fractions and (b) if separation of the very fine fraction could be achieved on a commercial basis by such industrially oriented methods as air classification. The results of the air classification and ultrasonic tests indicated that the very fine minus 325 mesh coal ash fraction and alkaline earth constituents of modified flyash could not be separated because they were of similar sizes which would not allow size separation. The heterogenous nature and widely varying particle sizes and densities prevented sharp separation of the material by air classification. Thus it must be concluded that benefication by sizing is of little value in upgrading modified flyash.

For information purposes, sizing tests data are given in Appendix A (Table A1 through A8).

Specific Gravity The results obtained from bench scale separation of modified flyash by heavy organic liquids indicated that beneficiation by specific gravity separation techniques would not be feasible. The greatest portion of the modified flyash lay within a 1.80 to 2.96 specific gravity range. As with sizing by air classification, the range of particle sizes and densities did not permit sharp separation of the modified flyash constituents. It was possible to separate fractions of the dry collected limestone modified flyash that contained more than 93 percent lime through a combination of sizing to plus 100 mesh and separating the lighter non-lime constituents of this material in tetrabromoethane having a specific gravity of 2.96. The plus 100 mesh, 2.96 sink fraction, however, represents less than 0.2 percent of this modified flyash sample and less than 0.5 percent of the lime present in the sample. Thus the combination of separation methods would only be applicable for obtaining small quantities of relatively pure calcined, sulfated limestone for experimental purposes.

Other results obtained from specific gravity tests were that silica, alumina and titanium dioxide concentrations decreased in the gravity increments as the specific gravity of the separating fluid increased. The converse was true for iron oxide, lime and magnesia. Silica, alumina and titanium dioxide reductions were substantial in the higher gravity fractions; however, significant amounts of these compounds remained in the other gravity increments. Sulfur was generally slightly enhanced in the 2.60 to 2.80 specific gravity range. Lime and magnesia values increased in the heavier (above 2.70) specific gravity fractions. The fineness of the materials resulted in very slow settling rates. In addition, it was determined that pre-wetting with a light nonpolar liquid such as carbon tetrachloride facilitated wetting the material with the heavy organic specific gravity solution thereby preventing agglomeration.

The raw, wet collected modified flyash samples could not be separated into specific gravity fractions as easily as the dry collected materials indicating that hydration or pozzolanic activity had cemented the constituents.

For informational purposes, chemical analyses of the specific gravity fractions are given in Appendix A (Tables A9 through A28).

Magnetic separation Occlusion of the very fine non-magnetic constituents of modified flyash in the magnetic field was so prevalent that an effective separation of the highly magnetic ferruginous constituents could not be made with available magnetic separation equipment.

Yields and chemical analyses of the feed and the magnetic fractions obtained during these tests are given in Appendix A (Tables A29 through A48). Iron concentrates ranging from 45 to 55 percent ferric oxide could be obtained by closely sizing the modified flyashes to 200 x 325 mesh and then separating the ferruginous materials from these size fractions at 3000 gauss magnetic field strength on a cross belt dry magnetic separator. The iron recovered in this manner, however, amounted to less than 15% of the ferric oxides present in the feed material.

Since the highest iron concentrates were obtained at a low magnetic field strength of 3000 gauss, further dry magnetic separation tests were run at lower field strengths of 1400 gauss, the lowest obtainable with available equipment. There was less iron concentration at 1400 gauss.

The wet magnetic separator used in these tests was a constant magnetic field device so that no correlation between magnetic field strength and chemical analyses of the wet magnetically separated fraction could be obtained. Magnetic occlusion, however, would be expected to be less with a wet separator because of the water medium.

Statistical evaluation of the yield and chemical analysis data given in Appendix A (Tables A29 through A48), for magnetic separation were undertaken in an attempt to correlate physical and chemical characteristics of the feed with the resultant magnetically separated product.(23) The evaluation procedure consisted of determining linear regression equations for the magnetic yield and each chemical compound analyzed in the fraction for both wet and dry magnetic separator data. Physical and chemical parameters and field strength variables were then deleted from these regression equations in singular steps. The reduction in the value of the square of the coefficient of correlation (R^2) with the deletion of each variable gave an indication of the effect of the deleted variable on the magnetic yield or chemical constituent in the yield. Statistical evaluations were obtained in this manner for both wet and dry separations.

The correlations indicated that the amount of material reporting in the magnetic fraction was a function of the magnetic field strength and the amount of sulfur trioxide in the feed rather than the feed iron content. The amount of iron reporting in the magnetic fraction was found to be a function of the silica, alumina and sulfur trioxide in the feed. This would indicate that the iron in the modified flyash had not been fluxed by the addition of limestone or dolomite to the boiler but was still physically interlocked in a glassy matrix of silica and alumina as found in normal flyash. In wet magnetic separation the amount of lime in the feed accounted for 40 percent of the variation in iron oxide content in the magnetic fraction and would indicate that there might be some attraction between the iron-rich fractions and the lime constituents in water. However, there was a high degree of dependence of magnesia yield in the magnetic fraction on the feed magnesia which probably indicates that there is substantially no agglomeration between flyash and magnesia particles.

Thus, it may be concluded that magnetic separation of modified flyash is not feasible and that there is no substantial agglomeration between the flyash and the lime or magnesia constituents. The absence of agglomeration and the indication that the coal ash constituents of modified flyash are still physically interlocked with themselves after the injection of limestone in the boiler would also lead to the conclusion that the same problems that exist in magnetic separation of normal flyash would also be present with modified flyash. Moreover, the dilution of injected limestone would make magnetic separation of ferruginous constituents economically less attractive than with normal flyashes.

Electrostatic Separation This method of beneficiation was undertaken to determine if upgrading could be achieved by exploitation of the electrical properties of the different constituents of modified flyash. The effect of wide variations in particle size, fineness of the particles and the variation in density of the particles could not be overcome to achieve upgrading to any significant extent. The extreme fineness of the particles caused considerable dusting as particles were blown about by the electrostatic field with the result that as much as 30 percent of some samples were lost during testing. Variations in size and density caused the particles to be projected off the electrostatic ground roll in varying trajectories with the result that the collection was indiscriminate.

Chemical and yield analysis of the electrostatic separation tests are given in Appendix A (Tables A49 through A68).

Lightweight Aggregate Production Bloating tests, to determine the usefulness of modified flyash in lightweight aggregate production, indicated that the modified flyash tested would not be suitable in its present state. This is due to the high concentration of the alkaline earths in the flyash. The alkaline earths serve as a flux and lower the melting point to such an extent that the modified flyash melts to a fluid of low viscosity before any bloating reactions can occur. None of the presently used separation methods successfully lower the alkaline earth content to an acceptable concentration for bloating; therefore, lightweight aggregate production by this method cannot be considered as a possible utilization method.

Smelting Excess lime prevents modified flyash from being considered as a smelter feed. The lime to iron ratio should be about one to ten to prevent excess slagging, however, the modified flyashes tested all had a lime to iron ratio of about one to four. Smelter concentrates containing more than 90 percent iron were recovered during testing but slagging prevented recovery of any substantial quantities of iron. These tests were carried out in both oxidizing and reducing furnaces at temperatures up to 1700°C.

Although no experimental tests were made, modified flyash might well serve as a ferruginous flux in pelletized and sintered blast furnace feeds if the transportation distance was short enough to allow modified flyash to be obtained economically and the quantities required remain the same. It would be necessary for the chemical make up of modified flyash to be such that

$$\frac{\%\mathrm{CaO} + \%\mathrm{MgO}}{\%\mathrm{Al_2O_3} + \%\mathrm{SiO_2}} \cong 1.0$$

and

$$\frac{\%\mathrm{CaO} + \%\mathrm{MgO}}{\%\mathrm{SiO_2}} \cong 1.45$$

otherwise additional materials such as lime fluxes and gravel might still be required(24). These ratios are within the conventional limits for the modified flyashes tested to date. A major advantage to be gained in utilization of modified flyash would be the contribution of iron from the modified flyash to the final raw pig iron product; however, the effect of sulfur on the resultant iron product and on air pollution from the blast furnace would have to be considered.

Alumina Recovery Investigations of alumina recovery from modified flyash in the lime-sinter process indicated that the ratios of lime to silica and lime to alumina could not be adjusted to within the optimum range required for good recovery. The lime sinter process involves the formation of a soluble calcium aluminate and insoluble dicalcium silicate by heating lime and calcined clay to a sintering temperature. The soluble calcium aluminate is then leached from the solid sinter. The ratio required for optimum formation of calcium aluminate and dicalcium silicate and the values found in modified flyashes studied to date are given in Appendix A (Table A69). With the exception of dolomite modified flyash samples DD, DW, CM and CI, the lime to silica ratio is low while the lime to alumina ratio is high which would preclude adjustment of these ratios by the addition of lime or silica. The addition of lime to samples DD, DW, CM and CI in sufficient quantities to obtain a good lime to silica ratio would result in excess lime with respect to alumina. In addition, the iron content of modified flyash is above the three percent maximum for raw material feeds in the lime-sinter process.

Experimental alumina recovery tests included simple hot water leaching, sintering with additional lime and extraction studies. Only small amounts of alumina were recovered in any test. Thus it must be concluded that alumina recovery by lime-sintering has little utilization potential.

FUTURE WORK

Work is continuing on contract PH 22-68-18 (Pilot Scale-Up Of Processes To Demonstrate Utilization of Pulverized Coal Flyash Modified By the Addition of Limestone-Dolomite Sulfur Oxides Removal Additives). The following areas are to be investigated under this contract.

1. The three main aspects of the ECMC process will be studied in greater detail in order to fully determine the potential for utilizing all fractions of modified flyash in this manner.
2. The area of flotation as pertaining to modified flyash is to be more completely researched in order to develop a working knowledge of the mechanism of separation and the best reagents and techniques required to obtain the maximum recovery of the lime constituent. As part of the flotation studies, preliminary kinetics of the carbonation reaction will be investigated.
3. The separation of other constituents in the modified flyash, particularly calcium sulfate, should be considered with the objective of adapting the ECMC process to wet collected modified flyash.
4. Utilization of the reject solids in the production of heat treated products in addition to mineral wool is to be studied.
5. A detailed investigation of the mechanism, kinetics, and thermodynamics of sulfur dioxide evolution from modified flyash in an oxidizing atmosphere is also to be investigated.

It is recommended that further studies on the utilization of modified flyash in the areas of concrete admixtures, soil stabilization and amendments, cement kiln raw materials and acid mine drainage neutralization be considered to determine if the detriments to utilization in these areas can be overcome.

The use of modified flyash in the production of both fired and unfired building materials also represents an area of utilization likely to hold potential. Fired structural building materials such as brick and block could probably be produced by the WVU-OCR process (25) which would avoid problems attendant to extension of nonplastic materials and take advantage of the lighter weight building product that results with this process. Unfired structural building products would most likely be produced by processes similar to the sand-lime process for the production of brick and block. The strength and durability of building products produced by this process depends upon the formation of calcium and aluminum silicates during autoclaving. It appears that coarse sand might be required to adjust the lime to silica ratio and particle size in this process.

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APPENDIX A

Chemical and Physical Analysis Results
For Various Beneficiation Methods And Utilization Procedures

TABLE A1

Chemical Analysis of Dry Sieved Size Fractions of Sample PID, Dry Collected Presque Isle Limestone Modified Flyash, St. Clair, Michigan

(Percent Weight)

Tyler Mesh	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	Head	30.85	13.70	11.59	0.68	33.58	1.49	2.20
+65	0.76	16.18	4.14	5.22	0.21	58.90	0.66	3.02
65 x 100	0.90	14.34	5.63	5.13	0.24	71.00	0.78	1.55
100 x 150	1.54	27.31	7.21	8.53	0.31	54.91	0.74	1.15
150 x 200	2.43	26.76	9.03	9.65	0.38	36.07	0.67	1.04
200 x 270	2.63	27.86	12.29	12.55	0.47	41.49	0.64	1.00
270 x 325	3.88	28.43	12.04	13.94	0.46	33.63	0.69	1.15
325 x 400	2.18	26.23	10.86	11.91	0.42	36.92	0.89	1.50
-400	85.66	31.44	11.32	12.77	0.56	31.35	1.08	2.34

TABLE A2

Chemical Analysis of Wet Sieved Size Fractions of Sample PIW, Wet Collected Presque Isle Limestone Modified Flyash, St. Clair, Michigan

(Percent Weight)

Tyler Mesh	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	Head	19.39	7.98	9.65	0.31	26.62	0.69	10.94
+65	2.71	13.23	4.59	6.23	0.22	50.02	0.60	3.65
65 x 100	2.14	20.19	7.35	7.04	0.31	39.60	0.64	2.93
100 x 150	2.86	25.71	10.21	8.10	0.40	34.42	0.78	3.18
150 x 200	4.46*	35.47	14.19	11.70	0.51	21.58	0.74	2.95
200 x 270	3.54	32.73	12.29	11.30	0.44	21.58	0.89	4.01
270 x 325	4.39	32.08	12.54	13.23	0.54	16.30	0.95	5.39
325 x 400	4.16	32.73	12.54	15.48	0.58	14.51	0.95	7.71
-400	75.71	30.20	14.19	11.50	0.53	21.08	1.00	12.54

* Some cementitious lumps present in +150 mesh sizes

TABLE A3

Chemical Analysis of Dry Sieved Size Fractions of Sample DD, Dry Collected Drummond Island Dolomite Modified Flyash, St. Clair, Michigan

(Percent Weight)

Tyler Mesh	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	Head	30.81	12.54	10.72	0.42	17.90	14.77	8.09
+65	0.35	27.86	11.09	10.53	0.42	10.71	8.79	3.13
65 x 100	0.44	34.77	10.64	10.72	0.49	9.53	6.87	2.12
100 x 150	1.04	45.17	15.40	15.22	0.62	10.71	5.92	2.02
150 x 200	1.90	38.45	16.72	16.04	0.58	8.68	6.22	2.09
200 x 270	2.01	34.77	13.62	15.76	0.56	9.09	7.22	2.81
270 x 325	3.67	34.77	13.34	15.76	0.57	15.56	14.41	4.03
325 x 400	2.42	27.86	11.79	13.00	0.48	24.82	16.71	5.87
-400	88.13	32.73	11.09	10.17	0.49	19.65	16.71	6.85

TABLE A4

Chemical Analysis of Wet Sieved Size Fractions of Sample DW, Wet Collected Drummond Island Dolomite Modified Flyash, St. Clair, Michigan

(Percent Weight)

Tyler Mesh	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	Head	23.34	9.03	9.99	0.43	13.84	9.24	18.68
+65	3.61	26.23	9.41	17.51	0.44	9.09	8.37	11.28
65 x 100	1.72	26.23	8.85	13.23	0.41	12.91	6.70	11.73
100 x 150	2.26	30.81	8.67	9.82	0.39	7.20	5.50	7.42
150 x 200	5.22*	32.73	11.09	10.91	0.43	6.87	8.16	6.57
200 x 270	2.79	25.71	10.21	10.72	0.43	8.09	7.97	7.56
270 x 325	6.06	24.69	9.22	10.91	0.39	11.22	11.25	12.94
325 x 400	3.33	22.78	9.03	8.53	0.36	17.90	11.82	21.45
-400	74.97	23.72	10.21	8.53	0.49	17.90	9.70	21.17

* Some cementitious lumps in +150 mesh sizes

TABLE A5

Chemical Analysis of Dry Ultrasonically Sieved Size Fractions of Sample PID, Dry Collected Presque Isle Limestone Modified Flyash, St. Clair, Michigan

(Percent Weight)

Size Fraction	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO
Feed	Head	30.85	13.70	11.59	0.68	33.58	1.49
+100	2.51	17.45	6.86	5.39	0.34	49.50	1.25
100 x 150	2.70	22.87	10.82	6.63	0.43	48.87	1.01
150 x 200	4.47	25.64	11.50	9.82	0.42	36.81	0.93
200 x 270	5.86	29.78	14.14	13.55	0.59	33.91	1.12
270 x 325	5.04	28.49	16.07	13.93	0.54	26.45	1.09
325 x 400	6.20	30.85	15.39	17.80	0.66	28.03	1.22
400 x 20u	24.60	28.75	14.44	16.41	0.67	31.63	1.49
20u x 10u	39.62	32.53	14.91	12.95	0.67	35.34	1.99
-10u	8.96	25.86	13.70	12.26	0.70	29.26	1.15

TABLE A6

Chemical Analysis of Dry Ultrasonically Sieved Size Fractions of Sample DD, Drummond Island Dolomite Modified Flyash, St. Clair, Michigan

(Percent Weight)

Size Fraction	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO
Feed	Head	30.81	12.54	10.72	0.42	17.90	14.77
+100	0.80	25.86	9.99	13.80	0.43	15.33	9.87
100 x 150	1.07	32.53	12.22	16.26	0.53	12.70	10.48
150 x 200	2.08	31.40	13.28	17.48	0.56	9.57	8.87
200 x 270	3.03	29.00	11.50	15.82	0.54	14.09	11.97
270 x 325	3.16	24.11	10.60	11.92	0.43	15.21	12.88
325 x 400	3.80	20.59	9.70	9.29	0.38	19.85	13.36
400 x 20u	23.02	23.69	12.61	13.43	0.50	22.63	23.79
20u x 10u	40.83	26.09	11.73	9.82	0.50	25.31	23.19
-10u	22.15	36.82	16.97	11.71	0.64	19.54	17.76

TABLE A7

ULTRASONIC SIEVING RECOVERY DATA FOR DRY COLLECTED LIMESTONE MODIFIED FLYASH SAMPLES OBTAINED FROM BABCOCK AND WILCOX, INC.

(Percent Weight)

Size Fraction	PHS 42	PHS 45	PHS 46	PHS 47
+100	0.041	0.362	0.354	0.022
100 x 150	0.170	0.511	0.391	0.077
150 x 200	0.455	0.789	0.422	0.067
200 x 270	1.340	1.753	0.569	0.108
270 x 325	1.577	2.597	1.500	0.252
325 x 400	1.553	4.506	2.269	0.662
400 x 20u	16.235	15.379	13.240	11.813
20 x 10u	35.121	41.975	34.951	45.059
-10u	25.320	17.856	26.409	17.778

TABLE A8
CHEMICAL ANALYSIS AND PARTICLE CHARACTERISTICS OF THE -325 MESH FRACTION OF MODIFIED FLYASH SEPARATED BY AIR CLASSIFICATION

			Particle Characteristics (Microns)				Chemical Characteristics					
Sample	1st Pass	2nd Pass	Smallest	Mean	Largest	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO
-325 PID	Coarse	Coarse	2.7	6.95	42.5	29.5	32.06	11.61	17.72	0.65	27.50	1.36
		Fine	3.0	8.68	39.4	19.0	35.06	11.66	11.64	0.72	33.40	1.68
	Fine	Coarse	3.1	11.97	37.1	20.8	33.91	11.82	10.04	0.64	30.55	1.59
		Fine	3.2	8.10	27.6	27.2	33.80	12.31	8.55	0.61	32.51	1.74
-325 DD	Coarse	Coarse				18.5	29.45	10.51	14.68	0.51	20.18	18.69
		Fine				20.8	30.84	10.87	8.80	0.53	24.79	28.07
	Fine	Coarse				17.0	31.11	11.96	9.39	0.58	28.48	22.11
		Fine				34.3	31.48	12.54	8.25	0.59	25.00	23.19
-325 PIW	Coarse	Coarse				28.0	31.09	10.08	18.59	0.66	18.32	1.41
		Fine				18.0	31.81	10.08	7.95	0.60	28.14	1.79
	Fine	Coarse				10.0	36.62	11.45	11.41	0.62	23.96	2.04
		Fine				12.0	27.40	9.03	6.25	0.48	30.72	1.85
-325 DW	Coarse	Coarse				24.0	27.63	10.55	19.29	0.60	14.43	7.44
		Fine				18.0	31.09	10.94	9.78	0.58	18.50	10.58
	Fine	Coarse				16.0	32.79	10.94	10.88	0.67	20.07	10.43
		Fine				28.0	28.07	10.17	6.78	0.58	17.07	10.28

TABLE A9

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF RAW, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID

(Percent Weight)

Sp. Gr. Fraction	Yield (wt.%)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	Head	30.85	13.70	11.59	0.68	33.58	1.49	2.20
1.80 F	5.80	46.29	18.20	5.88	1.03	6.06	0.98	0.63
1.80 x 2.00	4.20	45.99	18.36	5.36	1.01	7.22	0.94	1.08
2.00 x 2.20	4.00	45.99	18.84	6.00	1.00	8.94	1.15	1.05
2.20 x 2.40	6.60	37.68	15.29	4.22	0.32	19.07	1.05	1.50
2.40 x 2.60	19.60	36.62	13.16	4.49	0.43	29.08	1.30	2.00
2.60 x 2.65	4.40	27.63	13.13	7.20	0.49	40.29	1.82	3.58
2.65 x 2.70	4.00	27.63	11.01	6.51	0.24	44.24	1.62	3.90
2.70 x 2.75	9.40	24.40	9.80	7.34	0.39	47.51	1.70	3.23
2.75 x 2.80	11.40	20.24	9.11	8.87	0.39	49.25	1.56	3.18
2.80 x 2.96	20.60	15.46	7.95	11.41	0.39	54.27	1.45	2.85
2.96 Sink	10.00	9.95	4.01	26.46	0.18	49.25	1.25	1.40

TABLE A10

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF +100 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID (Percent Weight)

Sp. Gr. Fraction	Yield (Wt.%)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	1.66	15.18	4.95	5.17	0.23	65.45	0.72	2.23
1.80 F	13.40	23.17	9.03	3.34	0.39	7.28	0.70	1.40
1.80 x 2.00	4.00	22.17	8.32	3.45	0.38	8.86	0.66	1.58
2.00 x 2.20	10.80	29.96	9.62	4.17	0.38	25.00	0.80	0.93
2.20 x 2.40	18.00	4.48	1.97	2.68	0.16	85.01	0.80	1.55
2.40 x 2.60	17.20	4.79	2.82	2.74	0.16	81.67	1.03	2.20
2.60 x 2.65	6.00	20.43	3.08	3.37	0.20	75.44	1.04	2.00
2.65 x 2.70	3.60	13.84	4.24	3.96	0.16	68.01	1.15	2.60
2.70 x 2.75	3.60	18.94	6.67	7.57	0.32	56.31	1.60	3.45
2.75 x 2.80	3.00	21.58	8.02	9.50	0.39	45.30	1.72	4.05
2.80 x 2.96	10.20	16.30	5.13	5.47	0.23	62.22	1.75	5.03
2.96 Sink	10.20	9.52	3.53	6.71	0.17	93.48	2.13	3.90

TABLE A11

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF 100 x 200 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID (Percent Weight)

Sp. Gr. Fraction	Yield (Wt. %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	3.97	26.73	8.26	9.14	0.35	42.88	0.69	1.08
1.80 F	8.00	39.31	12.93	5.59	0.89	5.76	0.87	0.75
1.80 x 2.00	12.60	43.30	14.37	6.06	0.92	7.15	0.97	0.55
2.00 x 2.20	4.20	49.74	17.13	7.72	0.90	9.02	1.07	0.38
2.20 x 2.40	16.80	12.60	5.74	3.83	0.28	68.89	0.89	1.10
2.40 x 2.60	15.00	16.30	5.53	4.00	0.22	71.61	0.92	1.20
2.60 x 2.65	2.80	17.34	5.23	4.69	0.27	70.69	0.98	1.33
2.65 x 2.70	1.80	18.94	6.73	8.11	0.33	55.62	1.31	1.60
2.70 x 2.75	2.00	21.00	7.52	9.78	0.40	46.94	1.34	1.95
2.75 x 2.80	2.80	16.30	6.61	9.68	0.32	74.46	1.55	2.10
2.80 x 2.96	13.00	9.66	3.93	10.36	0.22	69.78	1.25	2.00
2.96 Sink	21.00	8.55	3.27	16.04	0.21	82.76	1.26	1.40

TABLE A12

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF 200 x 325 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID

(Percent Weight)

Sp. Gr. Fraction	Yield (Wt. %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	6.51	28.19	12.14	13.38	0.46	36.80	0.67	1.10
1.80 F	13.00	10.81	17.89	6.00	1.22	6.67	0.98	0.40
1.80 x 2.00	2.40	49.74	20.54	7.06	1.17	9.02	1.08	0.53
2.00 x 2.20	9.00	47.22	17.13	6.51	1.07	11.58	1.02	0.56
2.20 x 2.40	13.20	37.95	12.59	7.20	0.68	27.84	1.13	0.98
2.40 x 2.60	10.00	36.62	10.16	7.72	0.53	29.40	1.03	1.28
2.60 x 2.65	1.20	36.35	12.48	13.42	0.72	23.96	1.46	1.50
2.65 x 2.70	0.40	34.54	13.88	13.04	0.67	22.26	1.28	1.70
2.70 x 2.75	2.20	28.75	11.01	10.57	0.50	35.12	1.32	2.05
2.75 x 2.80	2.80	23.57	8.39	8.19	0.42	46.94	1.76	2.90
2.80 x 2.96	9.00	14.48	3.64	8.03	0.28	58.45	1.27	2.85
2.96 Sink	32.80	7.72	4.24	21.32	0.22	76.44	1.44	1.50

TABLE A13

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF -325 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID

(Percent Weight)

Sp. Gr. Fraction	Yield (Wt. %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	87.84	31.31	11.31	12.75	0.56	31.49	1.07	2.33
1.80 F	3.80	51.37	21.44	5.76	1.11	6.28	1.17	0.60
1.80 x 2.00	4.00	50.07	20.36	5.53	1.08	8.70	1.04	0.75
2.00 x 2.20	2.20	53.02	19.51	5.20	1.11	9.71	1.09	0.93
2.20 x 2.40	8.00	42.71	15.15	5.94	0.79	17.77	1.11	1.48
2.40 x 2.60	16.40	39.87	14.89	5.94	0.72	22.98	1.27	2.03
2.60 x 2.65	6.00	30.85	12.37	6.19	0.56	43.72	1.59	3.08
2.65 x 2.70	8.80	25.87	11.01	6.19	0.39	33.58	1.65	3.15
2.70 x 2.75	18.60	26.74	10.06	8.61	0.40	51.06	1.85	3.18
2.75 x 2.80	00.00	00.00	00.00	00.00	0.00	00.00	0.00	0.00
2.80 x 2.96	15.00	23.78	8.09	15.59	0.36	30.38	1.39	2.28
2.96 Sink	3.00	15.80	5.04	33.29	0.25	18.50	1.12	1.30

TABLE A14

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF HEAD SAMPLE,
WET COLLECTED, LIMESTONE MODIFIED FLYASH,
SAMPLE PIW

(Percent Weight)

Sp. Gr. Fraction	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	Head	19.39	7.98	9.65	0.31	26.62	0.69	10.94
1.80 F	0.2	IS*	0.00	0.00	0.00	00.00	0.00	00.00
1.80 x 2.00	0.0	00.00	0.00	0.00	0.00	00.00	0.00	00.00
2.00 x 2.20	0.0	00.00	0.00	0.00	0.00	00.00	0.00	00.00
2.20 x 2.40	0.0	00.00	0.00	0.00	0.00	00.00	0.00	00.00
2.40 x 2.45	8.4	32.66	12.25	4.89	0.53	26.92	1.70	11.43
2.45 x 2.50	1.6	20.33	8.44	4.03	0.50	37.45	1.88	16.08
2.50 x 2.55	19.8	19.29	10.27	8.14	0.45	32.29	1.33	12.63
2.55 x 2.60	61.8	20.86	8.53	11.72	0.40	26.48	1.24	11.55
2.60 x 2.65	0.4	17.36	8.53	15.58	0.38	27.37	1.06	12.83
2.65 x 2.70	0.6	IS	0.00	0.00	0.00	00.00	0.00	00.00
2.70 x 2.75	0.0	00.00	0.00	0.00	0.00	00.00	0.00	00.00
2.75 x 2.80	0.2	IS	0.00	0.00	0.00	00.00	0.00	00.00
2.80 x 2.96	0.2	IS	0.00	0.00	0.00	00.00	0.00	00.00
2.96 Sink	0.2	IS	0.00	0.00	0.00	00.00	0.00	00.00

* Insufficient Sample for Analysis

TABLE A15

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF +100 MESH, WET COLLECTED, LIMESTONE MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

Sp. Gr. Fraction	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	4.85	16.30	5.80	6.59	0.26	45.52	0.62	3.33
1.80 F	1.0	33.45	12.91	6.34	0.58	6.90	0.67	2.30
1.80 x 2.00	1.4	24.94	9.03	3.94	0.43	11.09	0.66	5.08
2.00 x 2.20	8.6	20.68	8.53	5.15	0.44	19.02	0.84	7.08
2.20 x 2.30	8.8	25.57	11.48	5.32	0.46	26.92	1.03	6.03
2.30 x 2.40	32.4	13.70	5.82	4.49	0.30	41.00	1.76	3.65
2.40 x 2.60	29.0	24.52	9.13	9.61	0.41	35.06	2.02	6.03
2.60 x 2.65	3.0	34.26	11.06	15.30	0.49	24.58	1.46	3.80
2.65 x 2.70	2.6	27.32	10.15	17.19	0.54	24.38	1.51	3.95
2.70 x 2.75	3.4	30.88	12.96	17.12	0.71	23.30	1.40	3.45
2.75 x 2.80	3.2	27.32	12.09	17.97	0.56	23.39	1.70	2.95
2.80 x 2.96	4.0	24.94	12.25	19.96	0.57	24.18	1.33	2.50
2.96 Sink	2.6	11.23	8.73	35.95	0.49	16.80	1.49	1.43

TABLE A16

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF 100 x 200 MESH, WET COLLECTED, LIMESTONE MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

Sp. Gr. Fraction	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	7.32	31.65	12.63	10.29	0.47	26.60	0.75	2.04
1.80 F	13.8	43.10	17.07	7.42	1.03	3.44	0.72	0.43
1.80 x 2.00	12.6	38.95	16.06	5.22	0.89	4.08	0.62	0.63
2.00 x 2.20	10.0	39.16	18.99	7.83	0.72	9.01	0.82	0.48
2.20 x 2.40	10.2	25.78	11.19	6.34	0.43	37.76	0.91	0.98
2.40 x 2.60	8.4	25.78	7.11	5.90	0.36	34.21	0.83	1.10
2.60 x 2.65	1.6	27.09	7.57	7.45	0.34	29.73	0.75	1.23
2.65 x 2.70	1.6	22.92	9.13	11.40	0.42	37.14	1.13	1.63
2.70 x 2.75	1.8	21.97	11.34	13.22	0.47	34.49	1.43	1.83
2.75 x 2.80	2.8	15.87	7.57	10.57	0.36	39.35	1.33	1.78
2.80 x 2.96	9.6	10.29	5.93	10.17	0.29	44.89	1.23	2.18
2.96 Sink	25.6	3.86	2.37	10.08	0.21	46.39	1.70	1.53

TABLE A17

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF 200 x 325 MESH, WET COLLECTED, LIMESTONE MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

Sp. Gr. Fraction	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	7.93	32.37	12.43	12.36	0.50	18.65	0.93	4.78
1.80 F	1.4	42.95	16.21	6.67	0.84	4.54	0.89	1.00
1.80 x 2.00	0.8	51.11	24.42	8.39	1.00	13.32	1.43	3.25
2.00 x 2.20	3.2	38.55	18.68	5.78	0.66	11.66	1.28	4.40
2.20 x 2.40	14.0	37.36	14.42	9.24	0.66	27.83	2.61	7.83
2.40 x 2.50	19.4	30.38	13.09	6.34	0.48	19.99	1.81	7.15
2.50 x 2.60	36.0	27.77	10.52	9.61	0.23	23.01	1.94	7.55
2.60 x 2.65	2.4	24.11	10.78	18.12	0.28	18.56	1.74	5.13
2.65 x 2.70	3.2	19.81	9.91	22.15	0.31	17.66	1.23	4.38
2.70 x 2.75	3.2	18.47	11.34	27.16	0.37	17.37	1.33	3.65
2.75 x 2.80	3.0	16.16	9.24	38.98	0.45	15.21	1.29	2.95
2.80 x 2.96	1.6	14.75	17.52	42.90	0.44	18.87	1.21	2.88
2.96 Sink	10.0	9.13	5.49	37.44	0.31	7.19	0.62	1.18

TABLE A18

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF -325 MESH, WET COLLECTED, LIMESTONE MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

Sp. Gr. Fraction	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	79.87	30.33	14.10	11.70	0.53	20.73	1.00	12.30
1.80 F	0.0							
1.80 x 2.00	0.0							
2.00 x 2.20	0.8	25.14	11.93	14.36	0.50	27.60	1.72	6.70
2.20 x 2.25	0.0							
2.25 x 2.30	0.0							
2.30 x 2.35	0.0							
2.35 x 2.40	84.0	21.78	9.79	10.57	0.45	30.22	1.36	11.78
2.40 x 2.60	0.0							
2.60 x 2.65	0.0							
2.65 x 2.70	0.0							
2.70 x 2.75	0.0							
2.75 x 2.80	13.4	18.79	8.25	14.89	0.40	32.02	2.20	2.90
2.80 x 2.96	0.0							
2.96 Sink	0.0							

TABLE A19

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF RAW, DRY-COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

Sp. Gr. Fraction	Yield (Wt.%)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	Head	30.81	12.54	10.72	0.42	17.90	14.77	8.09
1.80 F	2.00	51.69	20.54	6.92	0.97	4.95	1.76	0.85
1.80 x 2.00	4.00	45.08	18.84	6.64	1.02	4.91	2.40	1.48
2.00 x 2.20	1.00	47.22	18.52	8.03	0.92	6.22	2.76	I.S.*
2.20 x 2.40	2.60	50.39	17.43	7.34	1.16	7.15	2.87	1.40
2.40 x 2.60	5.60	47.84	17.89	8.11	0.81	12.14	10.14	3.75
2.60 x 2.65	3.80	34.29	12.81	6.06	0.61	23.22	23.18	7.13
2.65 x 2.70	6.20	26.96	9.97	5.64	0.48	20.28	23.67	8.08
2.70 x 2.75	19.00	27.85	9.53	6.85	0.48	25.82	20.95	8.70
2.75 x 2.80	20.00	26.74	10.34	5.88	0.48	24.22	17.37	8.63
2.80 x 2.96	20.80	22.96	8.39	12.80	0.47	24.74	29.61	8.05
2.96 Sink	6.60	15.96	7.38	41.34	0.42	14.58	13.07	3.90

*Insufficient Sample for Analysis

TABLE A20

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF +100 MESH, DRY-COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

Sp. Gr. Fraction	Yield (Wt. %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	0.79	31.70	10.84	10.63	0.46	10.05	7.72	2.60
1.80 F	10.00	26.09	10.43	5.82	0.53	5.25	1.06	1.78
1.80 x 2.00	14.00	31.09	11.31	5.47	0.62	4.95	1.08	1.58
2.00 x 2.20	11.20	51.37	17.89	8.36	1.11	5.62	2.15	0.90
2.20 x 2.40	5.20	46.60	17.73	14.07	1.02	7.61	3.32	3.23
2.40 x 2.60	9.00	38.22	10.05	10.16	0.55	11.69	9.85	3.40
2.60 x 2.65	5.20							I.S.*
2.65 x 2.70	5.80	46.29	11.31	15.54	0.64	10.95	7.25	I.S.*
2.70 x 2.75	9.20	40.71	13.75	20.37	0.74	11.36	11.56	2.65
2.75 x 2.80	1.00	35.57	13.63	17.11	0.67	18.32	16.19	I.S.*
2.80 x 2.96	7.40	31.33	11.21	17.59	0.64	18.69	16.77	4.63
2.96 Sink	18.60	17.69	6.43	13.29	0.32	26.66	29.61	5.50

*Insufficient Sample For Analysis

TABLE A21

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF 100 x 200 MESH, DRY-COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

Sp. Gr. Fraction	Yield (Wt.%)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	2.94	40.83	16.25	15.75	0.59	9.40	6.11	2.08
1.80 F	10.40	55.06	19.85	9.31	1.15	5.91	1.85	5.80
1.80 x 2.00	18.20	40.15	14.00	5.70	0.75	5.57	1.56	1.33
2.00 x 2.20	12.20	54.03	16.54	8.28	1.08	7.28	2.15	0.73
2.20 x 2.40	7.40	45.38	14.50	10.67	0.84	9.02	3.32	1.15
2.40 x 2.60	8.00	45.68	12.26	11.63	0.84	10.74	5.50	1.68
2.60 x 2.65	4.00	39.87	10.91	11.86	0.63	14.02	8.59	2.35
2.65 x 2.70	6.60	40.43	12.37	17.76	0.75	13.36	11.91	2.98
2.70 x 2.75	8.00	32.79	11.31	20.37	0.64	15.61	12.47	3.28
2.75 x 2.80	4.00	26.52	9.88	20.37	0.54	22.03	18.69	3.98
2.80 x 2.96	2.00	25.02	9.62	21.32	0.50	24.22	19.04	4.50
2.96 Sink	18.00	16.30	7.25	39.26	0.35	16.57	15.38	2.80

TABLE A22

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF 200 x 325 MESH, DRY-COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

Sp. Gr. Fraction	Yield (Wt. %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	5.68	34.77	13.44	15.76	0.57	13.33	11.86	3.69
1.80 F	4.00	53.70	21.26	7.64	1.17	6.06	2.40	0.65
1.80 x 2.00	5.60	41.56	14.50	6.31	0.89	5.63	2.79	1.80
2.00 x 2.20	10.40	44.18	14.76	7.42	0.84	7.74	5.63	1.95
2.20 x 2.40	14.00	37.41	12.26	7.72	0.66	12.98	9.19	2.73
2.40 x 2.60	20.00	28.53	9.36	8.69	0.48	15.31	15.38	3.38
2.60 x 2.65	6.00	32.05	11.11	12.44	0.56	19.87	19.77	4.55
2.65 x 2.70	9.20	26.31	10.82	16.34	0.50	18.50	15.65	5.28
2.70 x 2.75	7.80	22.36	11.01	27.66	0.50	15.77	11.73	4.45
2.75 x 2.80	1.00	20.24	9.36	28.92	0.44	14.29	13.93	5.10
2.80 x 2.96	9.80	19.12	10.34	40.63	0.46	15.77	10.89	3.55
2.96 Sink	6.80	15.13	7.05	56.57	0.37	8.94	5.02	1.48

TABLE A23

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF -325 MESH, DRY-COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DD (Percent Weight)

Sp. Gr Fraction	Yield (Wt. %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	90.55	32.59	11.10	10.25	0.49	19.78	16.71	6.83
1.80 F	1.60	54.72	22.00	7.06	1.10	2.56	1.81	1.05
1.80 x 2.00	1.40	49.10	19.51	5.42	0.90	3.28	2.31	1.25
2.00 x 2.20	1.80	51.69	19.67	6.19	0.89	4.73	2.78	1.20
2.20 x 2.40	1.20	50.07	16.83	6.92	0.90	6.10	2.71	I.S.*
2.40 x 2.60	4.60	41.85	12.15	7.64	0.68	12.85	9.85	4.23
2.60 x 2.65	6.00	26.74	9.97	5.59	0.49	20.07	18.01	6.78
2.65 x 2.70	14.80	28.53	11.11	6.38	0.48	20.28	18.34	6.83
2.70 x 2.75	25.00	25.45	10.34	6.44	0.44	19.67	18.69	6.88
2.75 x 2.80	30.00	22.96	8.87	9.13	0.46	23.46	17.69	6.93
2.80 x 2.96	12.40	19.12	9.11	19.82	0.39	22.74	19.04	6.03
2.96 Sink	Insufficient Sample for Analysis							

*Insufficient Sample For Analysis

TABLE A24

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF RAW, WET-COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

Sp. Gr. Fraction	Yield (Wt. %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	Head	23.24	9.03	9.99	0.43	13.84	9.24	18.68
1.80 F	0.40	Insufficient Sample for Analysis						2.35
1.80 x 2.00	0.20	Insufficient Sample for Analysis						7.73
2.00 x 2.20	5.60	31.57	9.11	10.57	0.53	15.61	9.99	18.80
2.20 x 2.25	1.60	40.15	12.70	7.42	0.69	9.79	10.14	8.75
2.25 x 2.30	0.20	Insufficient Sample for Analysis						
2.30 x 2.35	30.00	30.85	8.87	8.52	0.53	14.72	11.56	24.93
2.35 x 2.40	51.80	32.05	9.71	10.26	0.53	15.16	11.22	19.85
2.40 x 2.60	1.80	27.85	8.09	15.89	0.51	13.62	6.11	16.45
2.60 x 2.65	0.20	Insufficient Sample for Analysis						
2.65 x 2.70	0.60	Insufficient Sample for Analysis						
2.70 x 2.75	1.80	19.12	7.73	70.79	0.96	3.83	2.56	1.68
2.75 x 2.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.80 x 2.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.96 Sink	4.40	15.00	5.04	66.82	0.28	2.14	1.46	1.15

TABLE A25

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF +100 MESH, WET-COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

Sp. Gr. Fraction	Yield (Wt. %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	5.33	26.23	9.23	16.13	0.43	10.33	7.83	11.43
1.80 F	2.60	35.05	11.93	9.59	0.65	2.84	2.18	2.45
1.80 x 2.00	6.40	23.98	8.32	6.31	0.46	4.16	4.25	4.23
2.00 x 2.20	12.20	33.53	10.91	7.80	0.54	10.74	12.28	10.68
2.20 x 2.40	14.80	29.21	8.87	8.11	0.47	15.46	17.69	17.35
2.40 x 2.50	19.30	28.98	8.79	9.04	0.47	15.01	14.63	16.85
2.50 x 2.60	22.10	21.40	5.15	6.60	0.38	22.82	6.01	28.35
2.60 x 2.65	4.60	48.02	9.84	15.27	0.45	23.65	3.38	14.00
2.65 x 2.70	1.20	27.63	10.06	18.75	0.57	29.72	3.18	8.83
2.70 x 2.75	3.00	29.87	13.24	27.02	0.61	33.71	4.40	5.05
2.75 x 2.80	4.60	33.30	13.80	27.80	0.71	31.64	3.07	2.40
2.80 x 2.96	3.40	21.97	9.95	28.06	0.53	34.45	3.14	2.38
2.96 Sink	4.60	5.99	3.75	38.98	0.34	39.91	1.46	1.58

TABLE A26

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF 100 x 200 MESH, WET-COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

Sp. Gr. Fraction	Yield (Wt. %)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	7.48	32.15	10.36	10.58	0.42	6.97	7.35	6.61
1.80 F	4.00	46.06	20.27	7.08	0.94	4.22	1.82	1.28
1.80 x 2.00	2.20	38.31	15.50	6.38	0.76	4.98	4.28	4.20
2.00 x 2.20	9.60	40.39	17.80	6.54	0.67	11.00	13.03	7.25
2.20 x 2.25	14.80	33.45	14.63	4.25	0.69	10.46	10.92	7.78
2.25 x 2.30	5.20	29.89	15.06	4.64	0.53	12.26	14.31	9.35
2.30 x 2.35	1.80	37.54	15.74	12.77	0.77	4.22	6.00	6.28
2.35 x 2.40	43.30	29.65	10.52	6.09	0.48	19.34	10.21	17.68
2.40 x 2.60	3.40	33.30	12.89	11.67	0.59	22.96	6.19	11.60
2.60 x 2.65	0.40	26.21	11.48	17.97	0.51	7.36	4.73	0.00
2.65 x 2.70	0.80	23.93	14.82	36.52	0.67	18.83	5.66	5.08
2.70 x 2.75	1.40	14.48	10.52	38.67	0.42	6.19	4.33	2.45
2.75 x 2.80	0.80	33.30	15.74	26.01	0.80	17.78	6.00	2.28
2.80 x 2.96	4.00	29.58	13.80	28.87	0.79	18.01	6.29	1.85
2.96 Sink	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE A27

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF 200 x 325 MESH, WET COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

Sp. Gr. Fraction	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	8.85	25.33	9.65	10.99	0.41	10.38	10.36	11.25
1.80 F	0.2	IS*						
1.80 x 2.00	0.2	IS						
2.00 x 2.20	1.0	24.52	11.63	20.31	0.47	12.78	6.18	16.43
2.20 x 2.25	0.2	35.93	18.99	5.60	0.70	8.64	6.36	9.13
2.25 x 2.30	3.0	28.93	12.74	6.54	0.56	15.85	8.04	17.23
2.30 x 2.35	28.0	29.41	10.65	5.96	0.50	15.72	9.11	20.08
2.35 x 2.40	55.0	21.97	10.92	13.59	0.42	20.84	8.83	19.15
2.40 x 2.60	8.2	23.51	11.06	15.44	0.48	19.66	7.14	18.20
2.60 x 2.65	0.2	IS						
2.65 x 2.70	0.2	8.59	8.53	41.23	0.38	3.62	1.88	6.05
2.70 x 2.75	1.0	9.60	6.48	35.95	0.38	3.94	2.58	1.55
2.75 x 2.96	0.0	IS						
2.96 Sink	0.4	IS						

* Insufficient Sample for Analysis

TABLE A28

CHEMICAL ANALYSIS OF SPECIFIC GRAVITY FRACTIONS OF -325 MESH, WET COLLECTED, DOLOMITE MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

Sp. Gr. Fraction	Yield	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	SO_3
Feed	78.30	23.68	10.16	8.53	0.49	17.90	9.79	21.19
1.80 F	0.2	IS						
1.80 x 2.00	0.2	IS						
2.00 x 2.20	0.4	29.65	11.06	6.81	0.55	18.71	12.34	19.00
2.20 x 2.40	2.0	26.87	10.40	17.19	0.53	21.01	7.03	19.70
2.40 x 2.45	95.2	27.09	13.45	10.67	0.53	19.99	9.11	19.88
2.45 x 2.50	0.0							
2.50 x 2.55	0.0							
2.55 x 2.60	0.0							
2.60 x 2.65	0.4	IS						
2.65 x 2.70	0.2	IS						
2.70 x 2.75	0.0							
2.75 x 2.80	0.0							
2.80 x 2.96	0.0							
2.96 Sink	0.0							

TABLE A29

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED RAW, DRY-COLLECTED, LIMESTONE MODIFIED-FLYASH, SAMPLE PID

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	Head	33.60	59.60	50.40	56.80	30.00
SiO_2	30.85	32.54	27.40	30.38	32.05	27.63
Al_2O_3	13.70	12.88	12.42	12.31	13.47	10.65
Fe_2O_3	11.59	20.56	12.09	17.76	16.34	17.76
TiO_2	0.68	0.61	0.57	0.67	0.64	0.50
CaO	33.58	22.26	28.14	27.24	28.76	13.88
MgO	1.49	1.23	1.13	1.33	1.37	1.12
SO_3	2.20	3.85	3.97	3.75	3.83	1.33

TABLE A30

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED + 100 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	1.66*	12.00	38.00	40.00	42.00	75.00
SiO_2	15.18	29.91	36.88	35.05	30.38	21.00
Al_2O_3	4.95	11.24	12.53	12.20	10.17	7.23
Fe_2O_3	5.17	19.82	15.02	10.46	7.34	5.53
TiO_2	0.23	0.54	0.70	0.61	0.52	0.32
CaO	65.45	11.15	16.40	17.24	13.23	52.96
MgO	0.72	1.03	0.96	1.03	0.70	0.78
SO_3	2.23	2.48	2.43	2.40	3.03	1.48

* Percentage of raw sample coarser than 100 mesh

TABLE A31

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED 100 x 200 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID (Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	3.97*	20.00	40.00	46.00	52.00	79.60
SiO_2	26.73	26.31	39.87	39.04	36.62	25.02
Al_2O_3	8.26	12.88	13.84	13.47	12.65	10.55
Fe_2O_3	9.14	32.42	24.41	17.59	21.13	12.20
TiO_2	0.35	0.51	0.78	0.80	0.66	0.55
CaO	42.88	7.95	10.55	9.53	9.79	40.29
MgO	0.69	0.76	1.03	0.92	0.74	0.97
SO_3	1.08	0.53	0.60	0.75	0.73	1.18

* Percentage of raw sample falling into this size range

TABLE A32

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED 200 x 325 MESH, DRY-COLLECTED, LIMESTONE MODIFIED FLYASH, SAMPLE PID (Percent Weight)

		Magnetic Field Strength, Gauss					
	Feed	1400	3000	6000	9000	12000	Wet
Yield	6.51*	23.00	22.00	46.00	42.00	46.00	71.40
SiO_2	28.19	21.38	20.43	34.29	32.79	35.05	29.68
Al_2O_3	12.14	9.62	7.93	12.76	13.35	14.73	12.88
Fe_2O_3	13.38	48.61	53.35	34.77	30.22	31.58	22.31
TiO_2	0.46	0.58	0.42	0.73	0.72	0.72	0.65
CaO	36.80	7.74	6.67	8.78	8.86	9.44	12.98
MgO	0.67	0.79	0.78	0.85	0.80	0.80	1.00
SO_3	1.10	0.45	0.40	0.70	0.70	0.80	0.78

* Percentage of raw sample falling into this size range

TABLE A33

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED -325 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID
(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	87.84*	18.00	24.00	32.00	38.00	40.00
SiO_2	31.31	15.96	17.86	18.76	16.47	27.40
Al_2O_3	11.31	8.31	9.72	9.45	8.86	10.65
Fe_2O_3	12.75	53.80	45.81	47.39	41.70	16.95
TiO_2	0.56	0.44	0.47	0.50	0.48	0.60
CaO	31.49	7.81	9.53	9.27	9.44	28.76
MgO	1.07	0.80	0.78	0.72	0.69	1.37
SO_3	2.33	0.63	0.95	1.00	1.15	1.80

* Percentages of raw sample finer than 325 mesh

TABLE A34

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED RAW, WET-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE FIW

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	Head	86.00	94.40	92.40	92.40	46.15
SiO_2	19.39	27.63	21.77	26.31	25.23	24.86
Al_2O_3	7.98	10.06	9.28	10.06	9.97	10.63
Fe_2O_3	9.65	7.64	10.77	8.11	10.46	16.07
TiO_2	0.31	0.34	0.44	0.43	0.46	0.43
CaO	26.62	30.38	43.21	33.58	30.05	28.62
MgO	0.69	1.25	1.19	1.42	1.42	0.55
SO_3	10.94	13.80	13.65	13.58	13.43	10.38

TABLE A35

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, +100 MESH, WET-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	4.85*	60.00	82.00	86.00	94.00	96.00
SiO_2	16.30	16.15	25.93	22.14	21.01	20.57
Al_2O_3	5.80	8.99	9.69	9.42	10.44	9.07
Fe_2O_3	6.59	13.81	11.32	10.80	11.54	9.19
TiO_2	0.26	0.35	0.45	0.45	0.42	0.44
CaO	45.42	43.51	38.22	40.98	43.95	32.26
MgO	0.62	0.38	0.46	0.39	0.50	0.50
SO_3	3.33	5.93	5.55	5.25	5.40	4.75

* Percentage of raw sample coarser than 100 mesh

TABLE A36

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, 100 x 200 MESH, WET-COLLECTED, LIMESTONE MODIFIED FLYASH
SAMPLE PIW
(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	7.32*	42.00	78.00	82.00	84.00	90.00
SiO_2	31.65	20.57	35.93	29.11	32.00	35.55
Al_2O_3	12.63	12.70	13.82	11.90	11.90	13.43
Fe_2O_3	10.29	36.63	27.31	20.95	17.50	20.36
TiO_2	0.47	0.53	0.64	0.50	0.56	0.67
CaO	26.60	14.97	22.99	19.02	16.54	19.79
MgO	0.62	0.41	0.57	0.46	0.47	0.57
SO_3	2.04	4.13	5.30	5.18	5.53	2.76

* Percentage of raw sample falling into this size range

TABLE A37

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, 200 x 325 MESH, WET-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PIW (Percent Weight)

		Magnetic Field Strength, Gauss					
	Feed	1400	3000	6000	9000	12000	Wet
Yield	7.93*	33.00	38.00	60.00	66.00	74.00	82.00
SiO_2	32.37	18.76	15.65	20.57	21.46	26.48	29.73
Al_2O_3	12.43	9.03	9.51	11.90	11.90	12.12	11.68
Fe_2O_3	12.36	33.29	46.41	34.93	33.64	28.63	26.80
TiO_2	0.50	0.32	0.42	0.50	0.54	0.52	0.57
CaO	18.65	10.45	9.28	13.02	14.53	16.22	17.39
MgO	0.93	1.12	0.25	0.39	0.36	0.43	0.57
SO_3	4.78	3.83	3.20	4.80	5.23	5.63	3.18

* Percentages of raw sample falling into this size range

TABLE A38

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, -325 MESH, WET-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PIW
(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	79.87*	90.00	94.00	98.00	98.00	50.00
SiO_2	30.33	19.11	19.72	21.01	24.60	27.62
Al_2O_3	14.10	9.16	10.63	10.24	11.25	10.94
Fe_2O_3	11.70	10.20	10.10	10.49	10.90	16.69
TiO_2	0.53	0.47	0.45	0.44	0.47	0.54
CaO	20.73	31.63	33.91	31.94	38.22	22.76
MgO	1.00	0.44	0.51	0.46	0.60	0.60
SO_3	12.30	15.95	15.78	16.13	16.00	10.25

* Percentage of raw sample finer than 325 mesh

TABLE A39

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, RAW, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	Head	60.80	60.80	59.60	62.40	48.00
SiO_2	30.81	26.20	28.81	29.11	25.93	24.86
Al_2O_3	12.54	8.90	10.94	12.23	11.90	11.25
Fe_2O_3	10.72	8.52	11.32	13.30	11.32	18.88
TiO_2	0.42	0.43	0.44	0.46	0.42	0.53
CaO	17.90	16.71	19.60	18.10	20.19	9.47
MgO	14.77	15.02	16.84	15.77	14.30	12.97
SO_3	8.09	6.85	6.48	6.43	6.45	4.30

TABLE A40

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, +100 MESH, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DD
(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	0.79*	36.00	74.00	80.00	82.00	91.66
SiO_2	31.70	31.34	38.68	38.68	34.45	26.20
Al_2O_3	10.84	12.58	11.90	11.90	12.70	11.25
Fe_2O_3	10.63	24.61	17.17	14.90	12.97	10.80
TiO_2	0.46	0.72	0.66	0.74	0.72	0.50
CaO	10.05	8.25	7.38	7.53	7.83	6.55
MgO	7.72	4.71	3.51	3.46	4.27	6.32
SO_3	2.60	1.73	1.98	2.08	2.20	1.33

* Percentages of raw sample coarser than 100 mesh

TABLE A41

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, 100 x 200 MESH, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	2.94*	40.00	68.00	78.00	82.00	85.70
SiO_2	40.83	24.09	41.20	45.52	49.26	38.27
Al_2O_3	16.25	12.35	14.48	14.61	14.21	13.95
Fe_2O_3	15.75	35.60	25.08	21.55	22.17	17.83
TiO_2	0.59	0.61	0.73	0.54	0.77	0.69
CaO	9.40	6.42	6.95	7.38	7.99	7.02
MgO	6.11	2.12	2.66	3.63	3.46	4.87
SO_3	2.08	0.70	1.40	1.40	1.55	0.63

* Percentage of raw sample falling into this size range

TABLE A42

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, 200 x 325 MESH, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

		Magnetic Field Strength, Gauss					
	Feed	1400	3000	6000	9000	12000	Wet
Yield	5.68*	25.00	26.00	58.00	70.00	66.00	83.70
SiO_2	34.77	19.86	19.11	33.03	33.38	32.00	33.03
Al_2O_3	13.44	9.03	11.79	13.95	15.03	12.94	12.82
Fe_2O_3	15.76	41.34	48.66	27.57	24.38	24.61	20.36
TiO_2	0.57	0.52	0.55	0.59	0.58	0.67	0.60
CaO	13.33	6.97	6.81	9.01	8.57	7.53	8.40
MgO	11.86	2.33	1.83	5.55	5.73	3.88	9.20
SO_3	3.69	0.85	1.43	2.20	2.35	2.33	0.88

* Percentage of raw sample falling into this size range

TABLE A43

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, -325 MESH, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH
SAMPLE DD
(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	90.55*	48.00	76.00	76.00	78.00	32.00
SiO_2	32.59	29.11	24.86	25.66	25.39	38.21
Al_2O_3	11.10	9.96	11.04	12.01	11.79	13.69
Fe_2O_3	10.25	10.39	9.10	10.49	9.91	22.38
TiO_2	0.49	0.58	0.53	0.57	0.46	0.61
CaO	19.78	20.60	20.81	22.76	20.19	9.37
MgO	16.71	18.87	17.39	15.52	17.11	12.35
SO_3	6.83	7.00	6.65	6.65	6.35	3.98

* Percentage of raw sample finer than 325 mesh

TABLE A44

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED RAW, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	Head	74.80	88.80	88.00	85.60	44.23
SiO_2	23.24	29.91	25.02	24.81	26.31	24.34
Al_2O_3	9.03	11.01	10.82	9.19	9.71	11.25
Fe_2O_3	9.99	12.80	11.63	12.56	11.30	21.35
TiO_2	0.43	0.49	0.48	0.52	0.48	0.48
CaO	13.84	16.57	15.46	15.01	18.88	15.58
MgO	9.24	10.28	8.36	9.07	7.35	6.97
SO_3	18.68	18.93	19.05	19.08	18.98	16.88

TABLE A45

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, +100 MESH, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	5.33*	60.00	82.00	88.00	90.00	86.00
SiO_2	26.23	25.39	30.68	24.34	28.51	28.51
Al_2O_3	9.23	10.15	8.99	9.78	9.16	12.12
Fe_2O_3	16.13	23.69	16.22	18.52	17.33	18.00
TiO_2	0.43	0.58	0.50	0.50	0.48	0.50
CaO	10.33	14.97	15.74	14.25	12.89	11.67
MgO	7.83	9.05	9.67	8.21	6.97	7.95
SO_3	11.43	14.33	15.55	15.25	15.90	9.55

* Percentage of raw sample coarser than 100 mesh

TABLE A46

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, 100 x 200 MESH, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	3000	6000	9000	12000	Wet
Yield	7.48*	38.00	64.00	70.00	76.00	84.00
SiO_2	32.15	19.93	27.33	30.04	29.42	30.36
Al_2O_3	10.36	10.73	12.58	12.12	13.31	12.47
Fe_2O_3	10.58	43.85	26.05	24.61	22.60	20.95
TiO_2	0.42	0.50	0.54	0.50	0.58	0.57
CaO	6.97	7.60	7.91	7.38	8.40	8.23
MgO	7.35	2.94	4.00	4.64	5.11	6.43
SO_3	6.61	3.80	7.18	7.05	7.40	4.28

* Percentage of raw sample falling into this size range

TABLE A47

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, 200 x 325 MESH, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DW (Percent Weight)

		Magnetic Field Strength, Gauss					
	Feed	1400	3000	6000	9000	12000	Wet
Yield	8.85*	22.00	20.00	42.00	54.00	54.00	58.00
SiO_2	25.01	18.40	16.84	17.02	19.11	20.79	23.59
Al_2O_3	9.53	8.55	10.15	9.68	10.05	10.34	11.25
Fe_2O_3	10.85	37.92	53.50	29.74	25.08	28.10	24.38
TiO_2	0.41	0.52	0.48	0.44	0.47	0.47	0.47
CaO	10.23	9.10	7.38	10.15	12.39	13.55	11.55
MgO	10.21	3.75	1.80	5.83	6.12	5.92	7.09
SO_3	11.25	8.28	4.05	12.15	14.10	13.48	12.10

* Percentage of raw sample falling into this size range

TABLE A48

CHEMICAL ANALYSIS OF MAGNETICALLY SEPARATED, -325 MESH, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

		Magnetic Field Strength, Gauss				
	Feed	**3000**	**6000**	**9000**	**12000**	**Wet**
Yield	78.30*	86.00	92.00	96.00	98.00	32.00
SiO_2	23.68	23.10	21.91	19.72	21.68	17.94
Al_2O_3	10.16	9.60	9.87	10.24	9.51	11.14
Fe_2O_3	8.53	8.93	10.80	9.37	8.93	24.38
TiO_2	0.49	0.45	0.48	0.49	0.47	0.53
CaO	17.90	16.54	17.56	18.65	17.39	13.55
MgO	9.79	9.05	9.20	8.35	9.51	5.20
SO_3	21.19	20.50	20.00	20.58	20.68	14.98

* Percentage of raw sample finer than 325 mesh

TABLE A49

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED RAW,
DRY-COLLECTED, LIMESTONE-MODIFED FLYASH,
SAMPLE PID

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	Head	50.40	-	18.00	-	1.60	-
SiO_2	30.65	26.84	44.13	30.17	17.72	26.63	1.39
Al_2O_3	14.48	11.97	41.66	15.13	18.81	11.51	1.27
Fe_2O_3	11.50	13.02	57.06	18.26	28.58	15.44	2.15
TiO_2	0.62	0.51	41.46	0.58	16.84	0.55	1.42
CaO	34.42	34.72	50.84	33.61	17.58	14.45	0.67
MgO	1.08	1.72	80.27	1.31	21.83	0.77	1.14
SO_3	2.20	2.20	50.40	1.55	12.68	I.S.*	I.S.

*Insufficient Sample for Analysis

TABLE A50

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED +100 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	1.66	74.20	-	12.60	-	8.40	-
SiO_2	15.18	16.12	78.79	21.22	17.61	16.70	9.24
Al_2O_3	4.95	7.16	107.33	10.16	25.86	7.97	13.52
Fe_2O_3	5.17	3.27	46.93	10.94	26.66	5.68	9.23
TiO_2	0.23	0.29	93.56	0.37	20.27	0.35	12.78
CaO	65.45	48.29	54.75	35.28	6.79	6.02	0.77
MgO	0.72	1.08	111.30	1.72	30.10	0.46	5.37
SO_3	2.23	1.93	64.22	2.15	12.15	4.08	15.37

TABLE A51

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED 100 x 200 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	3.97	62.20	-	26.00	-	3.40	-
SiO_2	26.73	25.80	60.04	32.33	31.45	15.28	1.94
Al_2O_3	8.26	10.68	80.42	12.79	40.26	9.24	3.80
Fe_2O_3	9.14	8.90	60.57	14.87	42.30	8.90	3.31
TiO_2	0.35	0.51	90.63	0.57	42.34	0.31	3.01
CaO	42.88	39.82	57.76	29.76	18.04	5.92	0.47
MgO	0.69	1.02	91.95	0.78	29.39	0.42	2.07
SO_3	1.08	1.20	69.11	0.83	19.98	I.S.*	I.S.

*Insufficient Sample for Analysis

TABLE A52

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED 200 x 325 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	6.51	79.80	-	10.20	-	0.20	-
SiO_2	28.19	27.48	77.79	25.19	9.11	I.S.*	I.S.
Al_2O_3	12.14	14.91	0.00	12.13	0.00	I.S.	I.S.
Fe_2O_3	13.38	14.18	84.57	26.98	20.57	I.S.	I.S.
TiO_2	0.46	0.54	93.68	0.43	9.53	I.S.	I.S.
CaO	36.80	34.44	74.68	16.77	4.65	I.S.	I.S.
MgO	0.67	1.15	136.97	0.68	10.35	I.S.	I.S.
SO_3	1.10	1.20	87.05	0.90	8.35	I.S.	I.S.

*Insufficent Sample for Analysis

TABLE A53

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED -325 MESH, DRY-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PID

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	87.84	76.20	-	7.60	-	0.00	-
SiO_2	31.31	33.32	81.09	27.92	6.78	0.00	0.00
Al_2O_3	11.31	15.82	106.59	11.97	8.04	0.00	0.00
Fe_2O_3	12.75	14.87	88.87	16.49	9.83	0.00	0.00
TiO_2	0.56	0.62	84.36	0.63	8.55	0.00	0.00
CaO	31.49	31.50	76.22	28.12	6.79	0.00	0.00
MgO	1.07	1.94	138.16	1.36	9.66	0.00	0.00
SO_3	2.33	2.40	78.47	2.25	7.34	0.00	0.00

TABLE A54

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED RAW, WET-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	Head	38.00	-	58.20	-	1.60	-
SiO_2	19.39	26.00	50.95	23.04	69.16	23.23	1.92
Al_2O_3	7.98	12.45	59.29	11.37	82.92	9.80	1.96
Fe_2O_3	9.65	14.18	55.84	12.17	73.40	11.49	1.91
TiO_2	0.31	0.59	72.32	0.51	95.75	0.49	2.53
CaO	26.62	33.61	47.98	33.07	72.30	28.58	1.72
MgO	0.69	1.48	81.51	1.39	117.24	1.25	2.90
SO_3	10.94	12.93	44.91	13.30	70.76	I.S.*	I.S.*

* Insufficient Sample for Analysis

TABLE A55

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED +100 MESH, WET-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	4.85	69.40	-	26.20	-	3.60	-
SiO_2	16.30	23.42	99.71	22.85	36.73	17.91	3.96
Al_2O_3	5.80	10.42	124.68	11.82	53.39	9.80	6.08
Fe_2O_3	6.59	10.84	114.16	10.42	41.43	9.92	5.42
TiO_2	0.26	0.46	122.78	0.50	50.38	0.46	6.37
CaO	45.42	36.74	56.14	36.15	20.85	25.50	2.02
MgO	0.62	1.54	172.38	1.42	60.01	1.17	6.79
SO_3	3.33	5.15	107.33	5.78	45.48	I.S.*	I.S.*

* Insufficient Sample for Analysis

TABLE A56

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED 100 x 200 MESH, WET-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	7.32	66.20	-	25.80	-	0.20	-
SiO_2	31.65	31.12	65.09	27.70	22.58	I.S.*	I.S.
Al_2O_3	12.63	11.37	59.60	12.29	25.11	I.S.	I.S.
Fe_2O_3	10.29	16.34	105.12	18.60	46.64	I.S.	I.S.
TiO_2	0.47	0.59	83.10	0.54	29.64	I.S.	I.S.
CaO	26.60	22.37	55.67	24.28	23.55	I.S.	I.S.
MgO	0.62	1.58	168.70	1.29	53.68	I.S.	I.S.
S	2.04	5.35	173.61	6.08	76.89	I.S.	I.S.

* Insufficient Sample for Analysis

TABLE A57

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED 200 x 325 MESH, WET-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	7.93	77.40	-	18.00	-	0.20	-
SiO_2	32.37	28.58	68.34	23.61	13.13	I.S.*	I.S.
Al_2O_3	12.43	11.97	74.54	12.13	17.57	I.S.	I.S.
Fe_2O_3	12.36	19.66	123.11	25.54	37.19	I.S.	I.S.
TiO_2	0.50	0.53	82.04	0.46	16.56	I.S.	I.S.
CaO	18.65	18.36	76.20	20.10	19.40	I.S.	I.S.
MgO	0.93	1.65	137.32	1.38	26.71	I.S.	I.S.
SO_3	4.78	6.40	103.63	8.05	30.31	I.S.	I.S.

*Insufficient Sample for Analysis

TABLE A58

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED -325 MESH, WET-COLLECTED, LIMESTONE-MODIFIED FLYASH, SAMPLE PIW

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	79.87	13.80	-	56.20	-	30.00	-
SiO_2	30.33	24.59	11.[illegible]9	24.79	45.93	2[illegible].39	24.12
Al_2O_3	14.10	11.22	10.[illegible]8	13.14	52.37	10.81	23.00
Fe_2O_3	11.70	13.79	16.[illegible]7	12.17	58.46	11.38	29.18
TiO_2	0.53	0.61	15.88	0.57	60.44	0.52	29.43
CaO	20.73	31.25	20.80	33.61	91.12	27.44	39.71
MgO	1.00	1.50	20.70	1.50	84.30	1.48	44.40
SO_3	12.30	14.75	16.55	14.60	66.71	14.98	36.54

TABLE A59

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED RAW, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	Head	8.20	-	79.60	-	3.80	-
SiO_2	30.81	28.58	7.61	26.84	69.34	26.42	3.26
Al_2O_3	12.54	15.82	10.34	11.97	75.98	13.89	4.21
Fe_2O_3	10.72	10.63	8.13	11.27	83.68	12.77	4.53
TiO_2	0.42	0.61	11.91	0.60	113.71	0.56	5.07
CaO	17.90	24.28	11.12	24.28	107.97	25.70	5.46
MgO	14.77	12.81	7.11	11.17	60.20	12.37	3.18
SO_3	8.09	6.90	6.99	6.60	64.94	I.S.*	I.S.

*Insufficient Sample for Analysis

TABLE A60

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED +100 MESH, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	0.79	65.80	-	24.20	-	9.60	-
SiO_2	31.70	31.84	66.09	26.84	20.49	16.55	5.01
Al_2O_3	10.84	13.89	84.31	10.29	22.97	6.65	5.89
Fe_2O_3	10.63	11.60	71.80	17.76	40.43	5.22	4.71
TiO_2	0.46	0.64	91.55	0.45	23.67	0.32	6.68
CaO	10.05	15.57	101.94	8.67	20.88	2.79	2.67
MgO	7.72	9.19	78.33	6.88	21.57	1.08	1.34
SO_3	2.60	2.45	62.00	1.98	18.43	2.43	8.97

TABLE A61

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED 100 x 200 MESH, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	2.94	73.00	-	18.00	-	2.80	-
SiO_2	40.83	36.18	64.69	30.41	13.41	14.47	0.99
Al_2O_3	16.25	15.58	69.99	14.91	16.52	9.13	1.57
Fe_2O_3	15.75	18.78	88.05	24.67	28.52	7.58	1.36
TiO_2	0.59	0.71	87.85	0.62	18.92	0.33	1.57
CaO	9.40	11.54	89.62	8.82	16.89	1.83	0.55
MgO	6.11	7.19	85.90	5.96	17.56	0.83	0.38
SO_3	2.08	1.65	57.91	1.48	12.81	I.S.*	I.S.

*Insufficent Sample for Analysis

TABLE A62

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED 200 x 325 MESH, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	5.68	74.20	-	11.60	-	5.60	-
SiO_2	34.77	33.07	70.57	25.59	8.54	22.48	3.62
Al_2O_3	13.44	16.30	89.99	11.66	10.06	10.04	4.18
Fe_2O_3	15.76	18.10	85.22	25.80	18.99	29.48	10.48
TiO_2	0.57	0.65	84.61	0.47	9.56	0.45	4.42
CaO	13.33	16.23	90.34	9.28	8.08	6.34	2.66
MgO	11.86	9.54	59.69	6.31	6.17	3.63	1.71
SO_3	3.69	3.33	66.96	2.40	7.54	I.S.*	I.S.

*Insufficient Sample for Analysis

TABLE A63

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED -325 MESH, DRY-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DD

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	90.55	32.00	-	62.00	-	0.20	-
SiO_2	32.59	26.42	25.94	27.92	53.12	I.S.*	I.S.
Al_2O_3	11.10	10.16	29.29	11.82	66.02	I.S.	I.S.
Fe_2O_3	10.25	10.02	31.28	9.92	60.00	I.S.	I.S.
TiO_2	0.49	0.53	34.61	0.54	68.33	I.S.	I.S.
CaO	19.78	24.68	39.93	28.12	88.14	I.S.	I.S.
MgO	16.71	8.77	16.79	10.81	40.11	I.S.	I.S.
SO_3	6.83	6.63	31.06	6.70	60.82	I.S.	I.S.

*Insufficent Sample for Analysis

TABLE A64

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED RAW, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	Head	7.40	-	68.20	-	23.80	-
SiO_2	23.24	24.79	7.89	25.19	73.92	25.19	25.80
Al_2O_3	9.03	10.29	8.43	10.42	78.70	13.89	36.61
Fe_2O_3	9.99	9.73	7.21	10.12	69.09	14.05	33.47
TiO_2	0.43	0.49	8.43	0.48	76.13	0.57	31.55
CaO	13.84	20.95	11.20	18.67	92.00	22.92	39.41
MgO	9.24	7.99	6.40	9.19	67.83	10.12	26.07
SO_3	18.68	20.43	8.09	19.93	72.76	19.17	24.42

TABLE A65

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED +100 MESH, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	5.33	29.60	-	19.80	-	49.40	-
SiO_2	26.23	23.42	26.43	25.19	19.01	28.14	53.00
Al_2O_3	9.23	8.82	28.29	9.80	21.02	11.16	59.73
Fe_2O_3	16.13	10.02	18.39	17.12	21.02	20.03	61.34
TiO_2	0.43	0.45	30.98	0.53	24.40	0.54	62.04
CaO	10.33	25.08	71.87	19.45	37.28	11.44	54.71
MgO	7.83	6.78	25.63	7.75	19.60	7.87	49.65
SO_3	11.43	22.83	59.12	11.88	20.58	9.60	41.49

TABLE A66

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED 100 x 200 MESH, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH

SAMPLE DW

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	7.48	59.80	-	15.60	-	13.80	-
SiO_2	32.15	34.34	63.87	25.80	12.52	23.23	9.97
Al_2O_3	10.36	12.96	74.81	11.97	18.02	12.29	16.37
Fe_2O_3	10.58	14.32	80.94	18.78	27.69	23.80	31.04
TiO_2	0.42	0.61	86.85	0.48	17.83	0.51	16.76
CaO	6.97	12.13	104.07	10.88	24.35	10.52	20.83
MgO	7.35	7.41	60.29	8.63	18.32	8.24	15.47
SO_3	6.61	10.63	96.17	10.50	24.78	7.85	16.39

TABLE A67

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED 200 x 325 MESH, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

	Feed Analysis	Fraction One	Fract. One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	8.85	23.60	-	62.20	-	1.80	-
SiO_2	25.01	26.84	25.33	28.36	70.53	26.84	1.83
Al_2O_3	9.53	13.32	32.99	13.32	86.94	10.95	2.07
Fe_2O_3	10.85	13.02	28.32	14.32	82.09	13.79	2.29
TiO_2	0.41	0.50	28.78	0.52	78.89	0.51	2.24
CaO	10.23	21.29	49.11	18.67	113.52	17.92	3.15
MgO	10.21	11.17	25.82	11.17	68.05	9.49	1.67
SO_3	11.25	19.85	41.64	18.40	101.73	I.S.*	I.S.

* Insufficient Sample for Analysis

TABLE A68

CHEMICAL AND YIELD ANALYSIS OF ELECTROSTATICALLY SEPARATED -325 MESH, WET-COLLECTED, DOLOMITE-MODIFIED FLYASH, SAMPLE DW

(Percent Weight)

	Feed Analysis	Fraction One	Fract One Rec. Values	Fraction Two	Fract. Two Rec. Values	Tail Product	Tail Prod. Rec. Values
Yield	78.30	80.00	-	19.60	-	0.20	-
SiO_2	23.68	29.26	98.85	29.26	24.22	25.80	0.22
Al_2O_3	10.16	12.62	99.37	12.62	24.35	11.08	0.22
Fe_2O_3	8.53	12.41	116.39	11.60	26.65	10.02	0.23
TiO_2	0.49	0.57	93.06	0.58	23.20	0.51	0.21
CaO	17.90	23.49	104.98	23.49	25.72	19.94	0.22
MgO	9.79	10.12	82.70	10.81	21.64	9.80	0.20
SO_3	21.19	20.35	76.83	20.45	18.92	I.S.*	I.S.

*Insufficient Sample for Analysis

TABLE A69

RATIO OF LIME TO SILICA AND LIME TO ALUMINA REQUIRED FOR OPTIMUM RESULTS FOR ALUMINA RECOVERY BY THE LIME-SINTER PROCESS AND THOSE FOUND IN MODIFIED FLYASH

SAMPLE	$CaO:SiO_2$	$CaO:Al_2O_3$
Required	2:1	5:3
PID	1.09:1	7.35:3
PIW	1.34:1	9:78:3
DD	0.58:1	4.28:3
DW	0.59:1	4.60:3
PHS42	1.17:1	7.91:3
PHS45	1.76:1	11.69:3
PHS46	1.63:1	12.31:3
PHS47	2.14:1	13.62:3
D1D2	0.76:1	5.19:3
D1D3	0.79:1	5.23:3
CM	0.53:1	3:99:3
CI	0:54:1	4:55:3